



This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

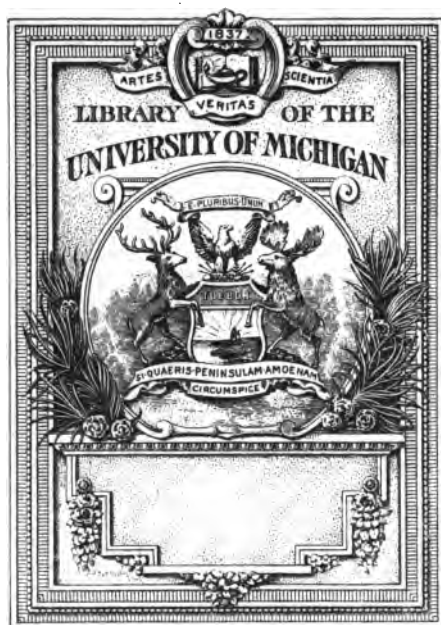
We also ask that you:

- + *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.
- + *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.
- + *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.
- + *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at <http://books.google.com/>

69



~~4. 6 2 4.~~

Astron. Obs.

Astronomical
Observatory

QB

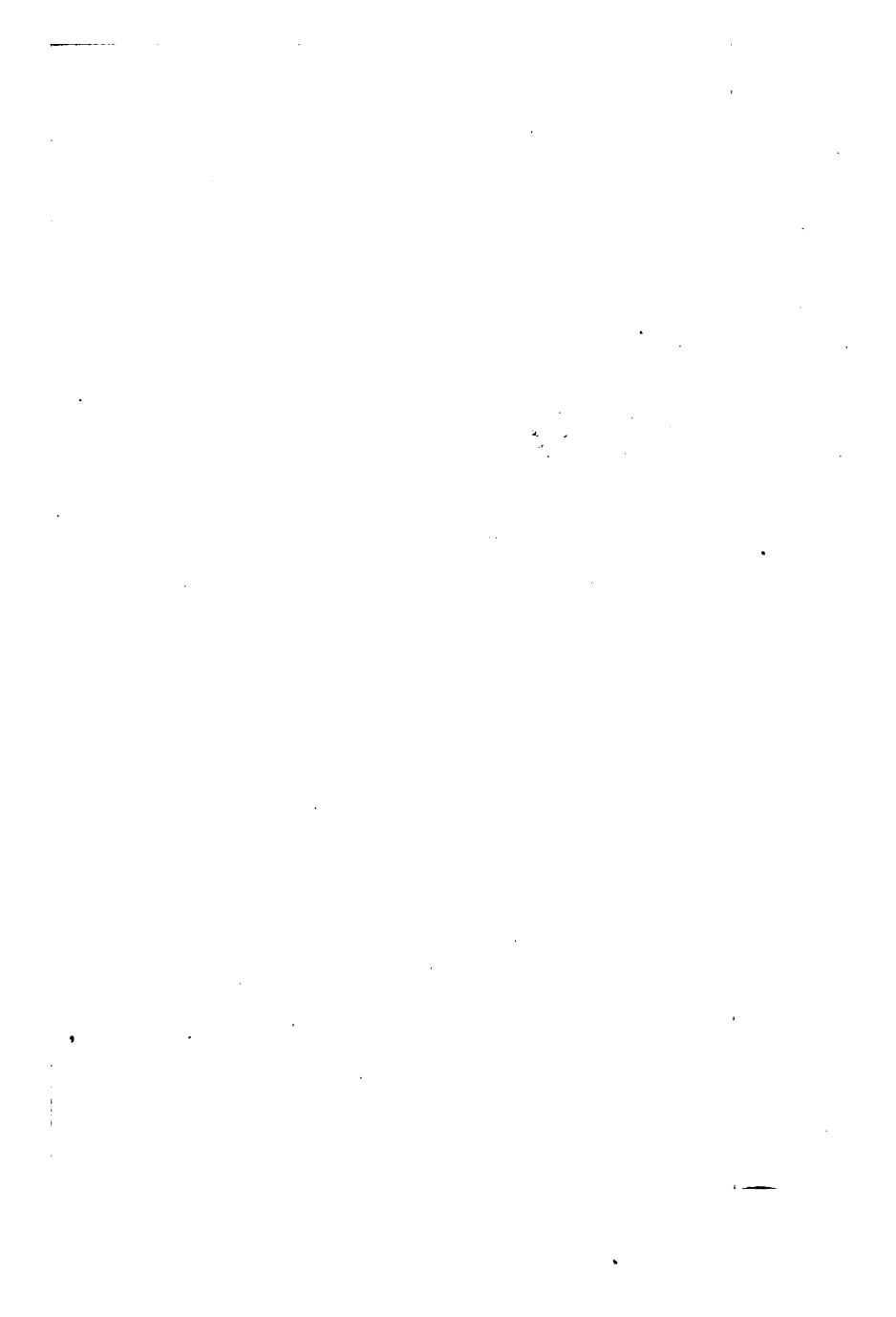
681

. G82

22

THE PLANET EARTH







Frontispiece.—The figure show

THE PLANET EARTH

AN ASTRONOMICAL INTRODUCTION

TO

5-145-1

GEOGRAPHY

BY

RICHARD A. GREGORY, F.R.A.S.

OXFORD UNIVERSITY EXTENSION LECTURER

AUTHOR OF 'ELEMENTARY PHYSIOGRAPHY' 'THE VAULT OF HEAVEN,' ETC.

London

MACMILLAN AND CO.

AND NEW YORK

1894

Rev. 4-1-38 *g.u.*

PREFACE

IN class-books of astronomy and geography, facts relating to the earth's movements and place in the universe are usually treated in an inadequate manner. Students are informed that the earth is a globe; that it rotates on an axis; revolves round the sun, and is one of a family of planets; but they are not taught these matters scientifically. The scientific method of observation and induction should be used in elementary astronomy as in other physical sciences. Celestial phenomena must be observed before the theories that explain them can be properly understood. This has been borne in mind in the design of the following pages. The first chapter deals with star-groups and the apparent diurnal motion of the celestial sphere. In the second chapter it is shown that all the phenomena previously described can be explained by the fact that the earth is a globe in rotation. The determination of the size

and mass of the earth is the subject of Chapter III. Then comes an account of the apparent annual motion of the sun among the stars, and the apparent motions of planets. And, finally, it is shown in Chapter V. that these appearances are easily explainable on the Copernican theory of the order of the universe.

For ages the whole of astronomy was concerned with the movements and varying dispositions of the heavenly bodies. It is hoped that this little book will help to revive the observational astronomy of pre-telescopic times. There is pleasure to be found in the mere contemplation of the heavens, and a knowledge of the causes of the varying appearances presented brings with it the keenest satisfaction.

Most of the illustrations have been specially drawn for the book, from my sketches, by Mr. W. H. Harvey, B.A. A few are from M. Flammarion's *Astronomical Myths*, and for permission to use these I am indebted to the publishers.

Commissary-General G. D. Lardner has kindly assisted me by reading the proof-sheets of the book, and by calling my attention to several points which had escaped my notice.

R. A. GREGORY.

WIMBLEDON, SURREY,
October 1894.

CONTENTS

CHAPTER I

THE HEAVENS WE SEE

Number of stars—Star-groups or constellations—Naming of stars—
The Plough or Ursa Major—The Pole-Star—Cassiopeia—Orion—
Taurus—The Pleiades—Canis Major—Canis Minor—Gemini—Leo
—Virgo—Bootes—Corona Borealis—Hercules—Lyra—Cygnus
—Aquila—Pegasus—Andromedæ—Perseus—Aurigæ—Diurnal
motion of the heavens—The celestial poles—Circumpolar stars—
Spheres of observation—The Pole-Star and terrestrial latitude

page 1

CHAPTER II

THE EARTH AS A SPINNING GLOBE

Early ideas concerning the shape of the earth—Convex form of the sea
surface—Circular form of the horizon—Dip of the horizon—Circum-
navigation not a proof of the earth's curvature—Form of earth's
shadow—Altitudes of the same stars observed at different places—
Succession of day and night—All bodies are pulled towards the
earth's centre—Daily motion of the sun across the sky—Early
ideas as to the sun's motion—The Copernican doctrine—Foucault's
pendulum experiment—Exact period of rotation of the earth—
Why stars are not seen in the daytime—Dawn and twilight—
The earth's polar and equatorial diameters—Cause of polar com-
pression

page 20

CHAPTER III

THE SIZE AND MASS OF THE EARTH

Measurement of angles—Relation of arcs to angles—Measurement of a base line—Triangulation—Arcs of meridian or latitude—Relation of circumference to diameter—Diameter of the earth—Determination of the polar compression of the earth—Pendulum observations—Surface and volume of the earth—Meaning of weight—Gravitational attraction—Principle of the Cavendish experiment—Results of observation—Density and weight of the earth page 43

CHAPTER IV

WANDERING STARS

Annual motion of the sun among the stars—The ecliptic—The zodiac—Origin of the signs of the zodiac—Annual variations of the sun's noonday altitude—The solstices and equinoxes—Variations of the sun's amplitude of rising and setting—The moon's motion among the stars—Evening stars—Apparent motions of "morning" and "evening" stars—The looped paths of planets—Conjunction and opposition page 59

CHAPTER V

THE ORDER OF THE UNIVERSE

The Ptolemaic theory of the universe—Geocentric views of Pythagoras and Aristarchus—Copernicus—His development of the true theory of the universe—Ability of the Copernican theory to explain all apparent motions—Cause of the succession of seasons—The mid-night sun—Precession of the equinoxes—Phases of Mercury and Venus—Kepler's laws—How to draw an ellipse—Elliptical form of planetary orbits—Planets move with varying velocity—The relation between the distances and periods of planets—The law of gravitation page 78

CHAPTER I

THE HEAVENS WE SEE

THE earth is a speck in the infinite ocean of space. Surrounding it at immense distances on all sides are the stars, each a sun comparable to our own in magnitude, but sunk so deep in the depths of space that it appears as a lucid point. Though it may seem a hopeless task to attempt to count the stars, in reality the number visible to the naked eye is comparatively small. On a very fine night it is possible to reckon between two and three thousand stars at one time, but such favourable opportunities are not of common occurrence. A little mist or fog is usually present which blots out all the fainter stars, reducing the number of those the light of which can pierce the veil to about one thousand. And though the glare of moonlight adds to the beauty of a night-scene, it assimilates the feeble beams of many of the distant suns and causes all to undergo an apparent diminution of brilliancy. By the invention of the telescope, however, the observable stellar universe became enormously increased, hence when Galileo turned his optic-tube towards the heavens he discovered "world beyond world, in infinite

extent, profusely scatter'd o'er the blue immense." Telescopes have increased in size since that day, and with the mighty instruments now at the disposal of astronomers something like one hundred millions of stars are brought within view.

One of the first circumstances that strikes the observer who directs his inquiring gaze heavenwards, is that the brighter stars form well-marked groups which constantly retain the same shape. A very conspicuous configuration or constellation of this kind can be seen when looking towards the north on any fine night. It is made up of seven stars, and, in general language, is known as the Plough or Charles' Wain. Astronomers name the group Ursa Major, that is, the Great Bear. To the ancients, this and other conspicuous groups of stars bore a fancied resemblance to figures of men and animals, or some peculiarity was attributed to them which was also possessed by characters in heathen mythology. The Egyptians, Chaldeans, and Chinese were the first peoples who divided up the stars in this manner, but the earliest systematic grouping is contained in the *Almagest*, a great work written by Ptolemy nearly eighteen hundred years ago. In that catalogue the stars are divided into forty-eight groups, most of them being named after characters connected with the voyage of the ship *Argo*. It requires a vivid imagination to construct these figures from the configuration of the stars. It is doubtful, indeed, whether any of the constellations were ever supposed really to resemble the characters whose names they bear. There would be mythological reasons why certain figures should appear near to each other in the sky, and it would be a matter of chance whether

the stars lent themselves to the required configuration or not, the artist using the existing material in any manner he pleased. The figures were probably sketched upon a globe to represent constellations, and only those stars which fell within the outlines of the drawings were assumed to belong to the constellation. This is strongly supported by the fact that many bright stars were not included in any constellation; thus a bright star named Arcturus is not contained in Ptolemy's constellation Bootes, to which it properly belongs.

In spite of the unscientific plan adopted by ancient astronomers in mapping the heavens, the arbitrary division is still retained for convenience. The constellations may thus be considered analogous to countries on the earth, with the stars as towns. The majority of the bright stars possess proper names, such, for example, as Regulus, Aldebaran, and Rigel, but another and a better method of designating them is by means of the letters of the Greek alphabet, giving the first letter (Alpha) to the brightest star in a constellation, the second to the next brightest, and so on. Thus, Regulus is α Leonis, that is, Alpha of the Lion constellation; Aldebaran is α Tauri, that is, Alpha of the Bull, and Rigel is β Orionis—Beta of Orion.

It is now possible to follow with interest a description of the arrangement of the stars in some of the chief constellations. But this portion of astronomy can only be properly understood by looking at the evening sky. All that can be done here is to point out conspicuous configurations of stars to act as celestial finger-posts.

The Great Bear constellation is always visible in England on a fine night, and is therefore a useful

starting-point. The seven stars which compose it are easily recognised when looking towards the north, and the two most distant from the curved tail serve to indicate the position of a star which should be familiar to



FIG. 1.—View of the sky looking north. To find the aspect of the circumpolar constellations at about 10 P.M. during any season of the year, turn the page until the name of the season is at the bottom.

every one. The objects in question are known as the "Pointers," because the line joining them points very nearly to the Pole-Star or North Star (Fig. 1). This star never sinks below the horizon of an observer in England, and when facing it we face the north. It appears to

occupy the same position in the sky night after night throughout the year, differing in this respect from all others—a peculiarity referred to by Shakespeare in the following lines :—

Constant as the northern star,
Of whose true-fix'd and resting quality
There is no fellow in the firmament.
The skies are painted with unnumber'd sparks,
They are all fire and every one doth shine,
But there's but one in all doth hold his place.

Near the Pole-Star can be seen two other fairly bright stars, known as the "Guards of the Pole."

After the Great Bear, the next most conspicuous group in the northern sky belongs to the constellation of Cassiopeia. Its characteristic form is that of a W—a configuration termed Cassiopeia's Chair. A line from the last star in the tail of the Great Bear— η Ursae Majoris—if carried through the Pole-Star and continued for about the same distance on the other side, leads to this group, the top of the W being directed towards the Pole. Whatever the position in which the Great Bear is seen, Cassiopeia appears on the opposite side of the Pole.

Between the Great Bear and the "Guards," and extending round to Cassiopeia, occur the constellations Draco and Cepheus. Neither of these groups are marked by any very definite figures, but it is not difficult to find the stars in them by reference to a map of the northern region of the sky.

The Great and Little Bears, and Cassiopeia, are always visible on a fine night in England. Sometimes they are high above the northern horizon, sometimes low down, but never invisible unless shut

off by the clouds, which are so common in this climate of ours. Draco and Cepheus and a few more constellations near them behave in a similar manner, and earn for themselves the term of "circumpolar constellations."

The constellation next in order of prominence in the evening sky is that of Orion. Unlike those we have been describing, it can only be seen during certain months of the year. About the middle of January three brilliant stars in a line can be seen in the south at ten o'clock. The configuration is so conspicuous that a glance upward is all that is required to recognise it. To the matter-of-fact Englishman the group is known as the Yard-Stick, but astronomers, following the lead of Ptolemy, name it the Belt of Orion (Fig. 2). A glorious constellation this, and one which has only to be seen to be remembered. Four bright stars in the form of an oblong surround the belt and mark different parts of the body of the giant Orion, the two above the belt indicating the positions of his two shoulders, whilst the two below locate his right knee and left foot respectively. Hanging from the belt is Orion's sword, represented in the sky by three small stars.

Orion's Belt shall guide us to other stars. Continue its direction upwards to about five times its length, and a bright star of a ruddy colour will be met. This is Aldebaran, the brightest star in the constellation of the Bull (Taurus). Carry the line still further, and that beautiful cluster of stars known as the Pleiades will be seen. Six stars can easily be distinguished with the naked eye, and as many as ten have been counted in the cluster by persons

gifted with keen vision. A small telescope will reveal about a hundred stars, and nearly three thousand have been found on a photograph of the group.



FIG. 2.—Some constellations visible when looking south at 10 P.M. about the middle of January. The names of stars are in small type.

By again using Orion's Belt, we can find the constellation of the Great Dog (Canis Major). The line of stars points downwards to an unmistakable object, —the brightest of all that bespangle the sky, the Dog

Star—Sirius. To the north-east of Sirius, another bright star, Procyon or α Canis Minoris, will be found. Betelgeuse (α Orionis), Sirius, and Procyon form a triangle, having sides of equal length. They are all bright stars, so there should be no difficulty in finding them.

The constellation Gemini or the Twins next claims our attention. It lies to the north-east of Orion. A line from Procyon carried towards the tail of the Great Bear passes near the two chief stars, Castor and Pollux, in the constellation. Pollux is about the same distance north of Procyon that Procyon is east of Betelgeuse, whilst Castor lies slightly to the north-west of his brother.

Leo, the Lion, is the chief constellation visible in the south at ten o'clock about the middle of March. In outline it bears a resemblance to an Egyptian sphinx. The Pointers produced backwards lead to this figure (Fig. 3). Regulus, the brightest star in the constellation, lies near the place where the directing line cuts the body of the Lion. Above it occurs a line of stars, curved like the blade of a sickle. Indeed, these stars form a very good sickle, with Regulus at the end of the handle. A line from Procyon, through Regulus, passes over Denebola, a fairly bright star in the Lion's tail.

The constellation Virgo, the Virgin, lies south and east of the Lion. A line drawn in a south-east direction from Denebola reaches Spica, the principal star in Virgo. There should be little difficulty in finding this object, for there are no other bright stars in the neighbourhood. Spica can also easily be found from the Great Bear configuration; for if the line

connecting the stars α and γ in this constellation be produced southwards in a slightly curved form, it will reach the required object.

The end of May sees the constellation Bootes due



FIG. 3.—Some of the constellations visible during summer. The names of stars are in small type.

south at ten o'clock. Its principal star, Arcturus, is almost as brilliant as Sirius, but of a different colour. By continuing the curve of the tail of the Great Bear the star is at once found. Another guide is formed by drawing a line from Regulus through Denebola,

and producing it until the reddish-coloured star is reached. A large equilateral triangle can be recognised in the heavens, with its corners marked by Spica, Denebola, and Arcturus, the last-named star being situated at the northern apex of the figure. In a line with the last two stars in the Great Bear's tail, and at a distance about twice as great as that separating them, γ Bootes will be found. This star forms one of the corners of a diamond-shaped figure composed of stars in Bootes.



FIG. 4.—Relative positions of the constellations Cygnus, Lyra, and Aquila.

of August and September

North-east of Bootes occurs a constellation which has been named the Northern Crown, or Corona Borealis. The stars in this group are arranged in the form of a semicircle, and are thus rendered easy of recognition. To the north-east again occurs the constellation Hercules, which, though wide in extent, contains no very bright stars.

Some fine constellations can be seen when looking towards the south at ten o'clock in the months

(Fig. 4). A brilliant bluish-coloured star called Vega attracts the attention of the most casual observer. It forms a triangle with the Pole-Star and Arcturus. Two fairly bright stars will be seen forming a small obtuse triangle with Vega, and the three represent the chief objects in the constellation Lyra.

Cygnus, the Swan, has the form of a cross, and lies close to Lyra. The brightest star in this constellation marks the top of the cross, and makes a right-angled triangle with the Pole-Star and Vega, itself being situated in the right angle.

The bright star Altair, in the constellation Aquila, can be seen on the meridian about ten o'clock in the beginning of September. A line from the Pole-Star, through the cross of Cygnus, if continued for about the same distance towards the south, leads to Altair—the middle of three stars in a line—all of which belong to the constellation of the Eagle.

An extremely well-marked group, covering an enormous area of sky, arrests the attention in October. Four stars in the form of a square, known as the Great Square of Pegasus, will be visible when looking towards the south about ten o'clock (Fig. 5). The group is so conspicuous that a directing line is hardly required to point it out. Should there be any difficulty, however, carry a line from the Pole-Star past the brightest side of the W in Cassiopeia, and the square will be found. By connecting the two stars which form the western edge of the square, and producing the line southwards for about three times the distance, Fomalhaut, a solitary bright star in the constellation of the Southern Fish, is located.

The four stars which make up the Great Square of

Pegasus do not all belong to this constellation. That in the north-east corner and nearest Cassiopeia is really Alpha Andromedae. A line from the Pole-



FIG. 5.—Relative positions of the constellations Pegasus, Andromeda, Perseus, and Cassiopeia.

Star, through the side of the W in Cassiopeia most distant from the Pole, indicates the position of this star. And it is worth remark that the stars on this line appear due south at the same time. The line

connecting them happens to lie very close to what may be termed the "Greenwich meridian" of the sky, for it is used in much the same way as the meridian which passes through Greenwich Observatory. One represents the starting line from which terrestrial longitudes are counted, the other roughly indicates the position of the zero from which astronomers reckon celestial "Right Ascensions."

From α Andromedae, and extending to the north-east under Cassiopeia, a curved line of stars can be made out. The first three stars belong to Andromeda, but that with which the line is terminated is the chief star in the constellation Perseus.

Perseus and Andromeda are best seen about the end of November. The brightest star in the former constellation is situated between two fainter stars, one to the north-west, the other to the south-east of it. A remarkable object in this constellation is the variable star Algol. It is in the right angle of a right-angled triangle which it forms with α Persei and γ Andromedae. In an interval of a little less than three days Algol periodically blazes out and then fades into comparative insignificance.

A line from γ Andromedae, if imagined to pass midway between Algol and α Persei, points out Capella in the constellation Auriga. Capella and Algol are at the top of a V-shaped configuration, having Aldebaran in the angle.

We have now made a journey round the celestial world, and pointed out some of the chief stars and groups of stars to be seen in the northern sky. It is as if you had been guided through the streets of a great city and shown the remarkable buildings which

adorned it. In a superficial survey, many objects of interest are passed in silence, but a framework is erected whereby the student will be able to find his way about the heavens.

The forms of the Great Bear, or of Cassiopeia, or of Orion, appear to be the same from year to year. Indeed, the positions of stars relatively to one another remain unchanged to the unaided vision, though each star is really in motion through space. A movement which can be seen, however, and one which must have been noticed by every intelligent observer, is that of the heavens from east to west. Face the north on any clear night and note the positions of the Great Bear and Cassiopeia at an interval of about two hours. The sky will appear to have rotated as a whole in the opposite direction to that in which the hands of a watch move. If the observation is made in the autumn, when the Great Bear is below the Pole-Star and Cassiopeia above it, the former group will be found to have moved towards the east, whilst the latter has experienced a shift westward. Six hours after making the first observation, the constellations will appear to have rotated through a right angle, and twelve hours after they will be seen to have described a semicircle in the sky.

The fierce rays of the sun obliterate the light of the stars during the day, but if this were not so, we should see the heavens perform a complete rotation round a point near the Pole-Star in a little less than twenty-four hours. The points about which the rotation appears to take place are called the North and South Celestial Poles. If the Pole-Star were situated exactly at one of these points

in the sky, it would remain motionless while all other stars were in apparent rotation. But since this star is at a short distance from the North Celestial Pole, it traverses a minute circle round the stationary point. All other stars behave in a similar manner.

If, when facing the north, you imagine one of the legs of a pair of compasses to be fixed in the position of the pole, while the other leg touched any star, then the circle which the compasses can be supposed to trace out in the sky is the circle along which that particular star always appears to travel. In other words, the radius of the circle of travel is determined by the distance of a star from the pole. Now let the legs of the compasses be opened to such an extent that when one extremity touches the pole the other is on the horizon. All the stars embraced by the circle described with this radius are always visible on a clear night, thus earning for it the title of "The Circle of Perpetual Apparition." A circle of the same size drawn round the South Celestial Pole includes within it stars which are perpetually invisible in England. Objects embraced by the former circle do not rise and set like other stars, in fact, they never sink beneath the horizon. Sometimes below the pole, at other times above it, sometimes to the east, and sometimes to the west of it, these "circumpolar" stars and constellations shine throughout the year, and are thereby distinguished from those only visible at certain seasons.

So far only the diurnal motions of circumpolar stars have been described. The facts thus obtained must now be extended to the whole sky. Again using a pair of compasses for the measurement of dimensions

upon the celestial sphere, let one leg be fixed pointing towards the pole of the heavens while the other is directed towards a star more distant from the pole than the pole is from the horizon. This star will describe a part of its daily or diurnal circle above the horizon, and part below it. Increase the angle between the legs, still keeping one extremity fixed at the pole, and a point will be reached when one leg is perpendicular to the other. Stars at this angular distance from the pole are on the celestial equator. One half of their daily circle of travel is performed above the horizon, the other half below it. They are the only bodies which rise due east and set due west all the year round. We have, in fact, stars north of the equator which rise north of east and set north of west, and stars south of the equator which rise south of east and set south of west. The first class are longer above than below the horizon, when observed in England; in the second class the reverse in the case, for stars belonging to it are longer below the horizon than above it. A third class, included in the circle of perpetual invisibility, never appear above our horizon.

The saving clause "in England" frequently used in the foregoing description of the apparent daily motions of the stars, needs some explanation. It is natural to assume that the movements would appear the same when viewed from any place on the earth, but, as a matter of fact, this is not the case. The changes in the sky first noticed by an observant traveller journeying southwards for a considerable distance, is that the Pole-Star sinks towards the northern horizon, while new stars make their appearance in the south. The oblique paths familiar to

all who watch the heavens become more and more upright until, when at the equator, all the stars are seen to rise straight up on the eastern horizon, and set in a similar manner on the western. Before this

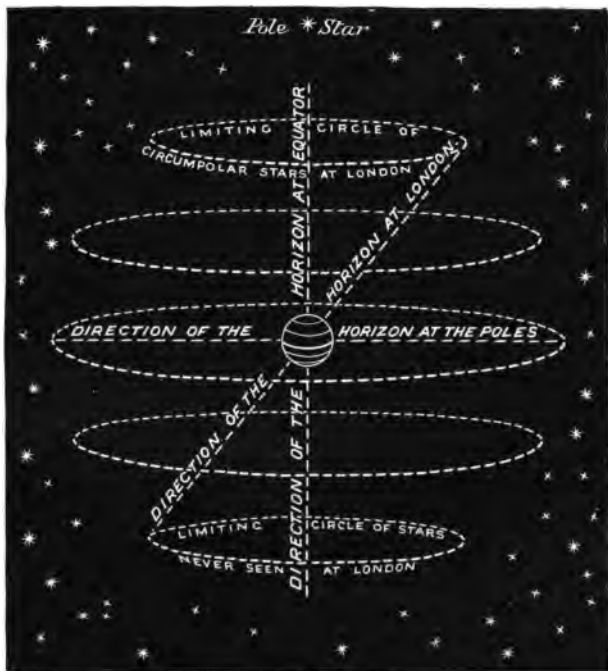


FIG. 6.—To explain why the altitude of the Pole-Star varies with latitude, and also to illustrate the apparent paths described by stars when viewed at the poles, at London, and at the equator.

point is reached, however, the Pole-Star will have sunk into the mists of the northern horizon. If the journey is made towards the North Pole of the earth, instead of being in the direction of the equator, a different appearance is again noted. Night after

night, the Pole-Star would appear higher above the horizon. The circle of perpetual apparition would thus daily increase in size. Stars which rose and set in the southern sky would disappear, while others which described part of their daily circle below the horizon would rise to the position of those which never set. And, could the North Pole be reached, the observer would see the Pole-Star overhead. In concentric circles all the stars would appear to travel round the celestial pole, the diameters of the circles increasing in size from this stationary point down to the horizon (Fig. 6).

The North Pole of the heavens is on the horizon of an observer at the equator. It appears higher and higher in the sky as a journey is made northwards, and, when the north pole is reached, it will be exactly overhead. There is, in fact, a close connection between latitude and the angular distance of the celestial pole from the horizon. The latitude, or distance from the equator, of any spot on the earth is equal to the altitude of the celestial pole at that place. Hence, wherever you may be, a rough determination of the latitude of the place can be made by noticing the height of the Pole-Star above the horizon.

SYNOPSIS OF CHAPTER I

The number of stars visible to the naked eye at any one time is about 2500. With the largest telescopes 100,000,000 can be seen.

Constellations are groups into which astronomers have arranged the stars according to their place on the sky. Ptolemy (140 A.D.) named forty-eight groups, and about twenty names since added are now accepted.

The names of the brightest stars visible from England are as follows :—

<i>α</i> Canis Majoris or Sirius	<i>α</i> Tauri or Aldebaran
<i>α</i> Bootes or Arcturus	<i>α</i> Scorpii or Antares
<i>β</i> Orionis or Rigel	<i>α</i> Aquilae or Altair
<i>α</i> Aurigae or Capella	<i>α</i> Virginis or Spica
<i>α</i> Lyrae or Vega	<i>α</i> Piscis Australis or Fomalhaut
<i>α</i> Canis Minoris or Procyon	<i>β</i> Geminorum or Pollux
<i>α</i> Orionis or Betelgeuse	<i>α</i> Leonis or Regulus
<i>α</i> Eridanus or Acharnar	<i>α</i> Geminorum or Castor

The relative positions of stars remain seemingly unaltered throughout the year, but the configurations change in centuries owing to the fact that each star is rapidly moving through space.

The heavens appear to rotate once in a little less than twenty-four hours round two points known as the celestial poles. The Pole-Star is near the north celestial pole, but the position of the south celestial pole is not similarly distinguished.

The celestial poles are the two points in the sky possessing no diurnal motion; the celestial equator is midway between them.

The apparent motions of the stars differ in character when observed from different places on the earth. To a person at the equator the stars seem to rise straight up and set straight down; at the poles the stars describe circles parallel to the horizon. In middle latitudes there are (1) stars which never set; (2) stars which never rise; (3) stars which both rise and set.

A determination of latitude on the earth can be made by observing the altitude, or angular distance, of the pole above the horizon.

Right Ascension is analogous to terrestrial longitude, and is reckoned along the celestial equator from a certain point in the sky.

CHAPTER II

THE EARTH AS A SPINNING GLOBE

To primitive Man, as to a child, nothing could appear more convincing than that the earth was a vast plain upon which a solid black vault was resting.

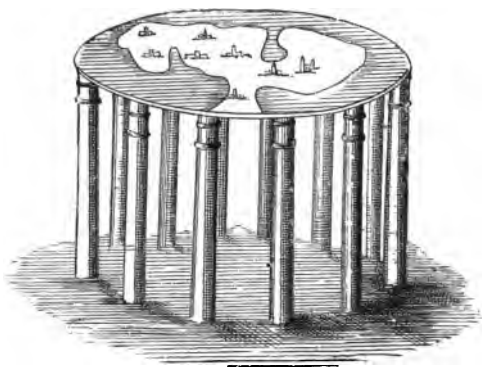


FIG. 7.—Old idea as to the shape and foundations of the earth.

His world was bounded by his horizon, and the immense proportions of starry space were reduced to the proportions of a dome like that which topped a mighty house. But, with the march of time, men's ideas became enlarged. Travellers found that, however long their journeys, "the end of the world" and

the heaven which they hoped to touch, were as far off as when they set out.

Many curious ideas have been held with regard to the shape and foundations of the earth. The Hindoo priests taught that the earth was flat, and supported on twelve pillars, which theory they ingeniously turned to their own advantage by asserting that the pillars were kept upright by means of sacrifices to the gods (Fig. 7). Earthquakes were thus ascribed to a falling

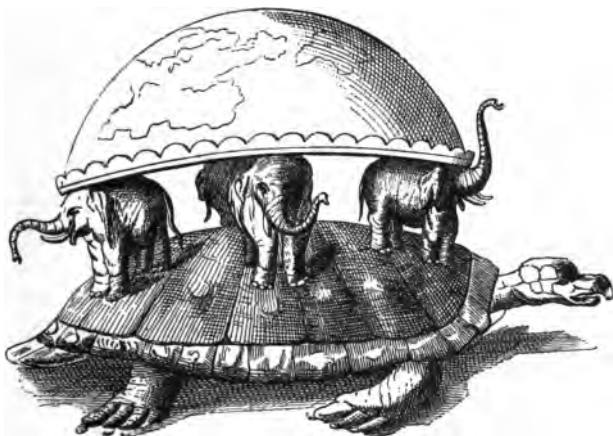


FIG. 8.—“The Hindoos represented the earth as a hemisphere supported by four elephants standing upon the back of a tortoise.”

off of sacrificial subscriptions. The Hindoos also represented the earth as a hemisphere supported by four elephants standing upon the back of a tortoise (Fig. 8). But this, to a great extent, may be allegorical, the elephants representing the four cardinal points, while the tortoise symbolised strength or eternity. Anaximander taught that the earth was drum-shaped, with only the top of the drum

inhabited. This world was supposed to rest upon compressed air, but what was beneath the air was left out of the question. The earth has also been imagined to be cubical—like a dice—egg-shaped, and triangular; but the general opinion for ages was that it was flat, that the visible horizon—the line where earth and sky appear to meet—marked the bounds of the earth, that the heavens and earth above the ocean represented the whole creation, and that all below the ocean was Hades.

One of the most apparent indications that the surface of our globe is curved is afforded by the form of the surface of the sea. Nine hundred years before the commencement of our era, Homer remarked that the sea was convex, but in spite of this, both he and the writers of his day believed the earth to be a circular plain surrounded by an ocean stream. A clear proof that the earth is more or less globular in shape is deduced from the fact that the horizon is always bounded by a circle. This outline cannot usually be traced upon the land, on account of local depressions and elevations, but on the sea, where nothing interrupts the view, the distance of the boundary of vision is the same in every direction. This distance, however, increases with the height of the observer above the sea surface (Fig. 9). Every boy knows that a whaling vessel has a "crow's nest" fixed high up on one of its masts, in which a seaman looks out for the monster of the deep. The mariner thus stationed has a much more extended view than his fellows. He is able to see beyond their horizons, and so often catches sight of objects to them invisible. The visible horizon, then, is a circle. At the equator, in the Antarctic, or in

the Atlantic Ocean, the result is the same. From this it must be concluded that the earth is a large ball, for if we lived on a body of any other shape, our horizon could not from every point appear circular.

In very early days men sailed on the sea in ships. "Over the bar and out of the bay" they went, and the watchers from the shore then, as now, saw them

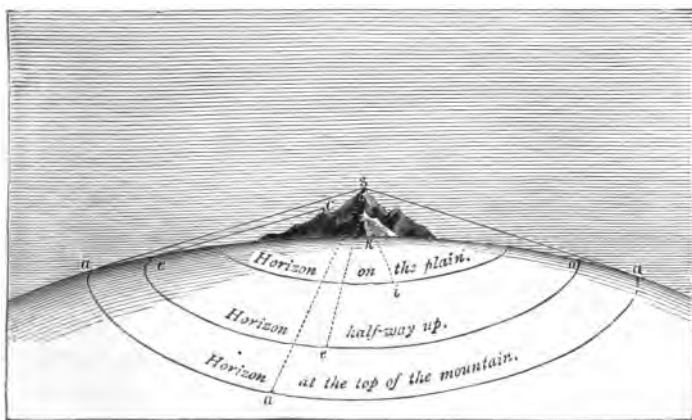


FIG. 9.—A clear proof that the earth is more or less globular in shape is deduced from the fact that the horizon is always bounded by a circle.

sink out of sight. Were the earth a level surface, an outward-bound vessel would gradually fade away. The rigging and masts would first become invisible, and the hull would be seen long after they had disappeared. But the reverse is found to be the case. On a clear day, at the seaside, a small telescope will show the topmasts of ships rising above the horizon, while the lower parts are quite out of sight (Fig. 10). Evidently a flat surface is at variance with these simple observations. The existence of a curved surface,

and of a curved surface only, will explain the facts. It is rather unfortunate, however, that most elementary books on geography, and many dealing with astronomy, should quote the sinking of ships below the horizon as a *proof* that the earth is a globe, whereas it only indicates that the surface is curved.



FIG. 10.—The fact that an outward-bound ship appears to sink below the horizon indicates that the earth's surface is curved.

The fact that the earth has been circumnavigated is also generally stated to be a proof of its globular form. There are still a few people who believe the earth is flat, and to them the credit is due of having found out all the weak points in the arguments against their view. Circumnavigation has been effectually disposed of. We know that by continuing on a due east or due west course for a long enough period of

time, a vessel returns to the place from which she started, and we say she has sailed round the world. The proper direction is determined by observations of the position of a compass needle. Now, suppose we lived upon the flat surface of an earth shaped like a Cheddar cheese; and suppose, also, that a compass needle always set itself in the direction of a line drawn from the centre of the surface to the outer edge, with the North Pole pointing towards the centre. A vessel sailing due east or west under such circumstances would describe a circle round the centre, and so would return to the starting-point. It would have circumnavigated the earth.

Two facts known to the ancients prove indisputably that the earth is nearly, if not quite, spherical. One is the appearance of the moon when she is eclipsed. From time to time the full moon passes into a shadow and loses its light for a couple of hours. The outline of the shadow which appears on the lunar disc, is always circular (Fig. 11). This is a very important circumstance. Only one figure throws a round shadow under all conditions, and that is a globe. The shadow into which the moon passes must therefore be the shadow of a large ball. Early astronomers knew that an eclipse of the moon was caused by the moon entering the shadow of the earth. With this knowledge, and the facts of observation, it was possible to place the earth's globularity beyond the possibility of doubt.

Another fact which results from the earth's spherical form is that the same stars have different altitudes when observed from different latitudes. If the earth were flat, the altitudes of stars would be the same from whatever place they were viewed, but the

earliest navigators found that this was not the case. When sailing southwards the stars in the northern sky appear lower and lower every night, and stars not previously seen shine out in the south. Let us



FIG. 11.—Photograph of an eclipse of the moon, showing the curved form of the earth's shadow.

assume that the earth is a globe surrounded by stars fixed in the celestial vault. A star exactly overhead at any place is on the horizon of an observer situated one-quarter of the distance round the globe in a north and south direction, and an observer at the Antipodes has his feet pointing to the same star. This indi-

vidual cannot, of course, see the star, because the earth is in the way. Now, the same amount of north and south movement produces very nearly the same change in all latitudes. This is a clear indication that the earth is *very nearly* circular in a north and south direction. If it were *exactly* circular the same amount of journeying in a north and south direction would produce exactly the same effect on the altitudes of stars, whether the starting-point be "Greenland's icy mountains or India's coral strand."

To dwellers on a flat earth, the sun would be simultaneously visible from all parts as soon as he appeared above the edge. But observations show that this is not the case. When the sun reaches its highest point at Greenwich it is rising to the people at St. Louis and setting at Calcutta. "It is mid-day," we telegraph to New Zealand. "With us it is midnight," the New Zealanders answer from their watch-towers. Twelve hours later the orb of day shines on the opposite side of the earth, and the people there enjoy its light, while our hemisphere is shrouded in darkness. In a day the sun appears to pass completely round the earth, hence in an hour a twenty-fourth part of a complete circle, that is, fifteen degrees (15°), is described (Fig. 12). The same fraction of the whole is passed over in the same time on all sides of the earth, and from this it is concluded that the world we live on is more or less round to the east and west, as well as north and south.

Sufficient has now been said to prove that the earth is a gigantic ball floating as it were in space, but without foundation or support of any kind (Fig. 13). Many people have a difficulty in understanding how

it is possible to live on a ball without slipping off. The difficulty arises, in the first place, from a misconception of the dimensions of our globe. The amount of slope is only eight inches in a mile, hence, if one end of a rod a mile long be imagined to lie upon the sea at any point, and the rod is supposed to keep perfectly straight, the other end would be found eight inches above the surface. Even this dip of the horizon often presents a

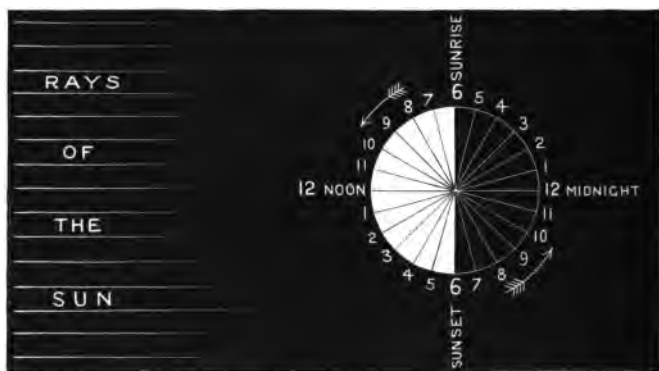


FIG. 12.—To explain the succession of day and night. If London is supposed to be at the point marked "12 noon," the numerals represent the times at places to the east and west of it. The reader should imagine himself in space and looking down upon the earth's north pole.

difficulty. That "water finds its own level" is a saying familiar to all. Yet it appears to be at variance with the facts, for the level of water, in the sense that the expression is commonly used, is never the same at any two places. What *is* true, however, is that a plumb-line at any place points towards the centre of the earth. The weight at the end of the line is attracted by the earth. It behaves as if all the force of attraction were concentrated at the earth's centre. Every

particle of matter on the earth, whether solid, liquid, or gaseous, is attracted by every other particle, and the result is a uniform pull to the earth's centre.

The mountain torrent rushes helter-skelter along its bed towards lower levels. Through valley and plain

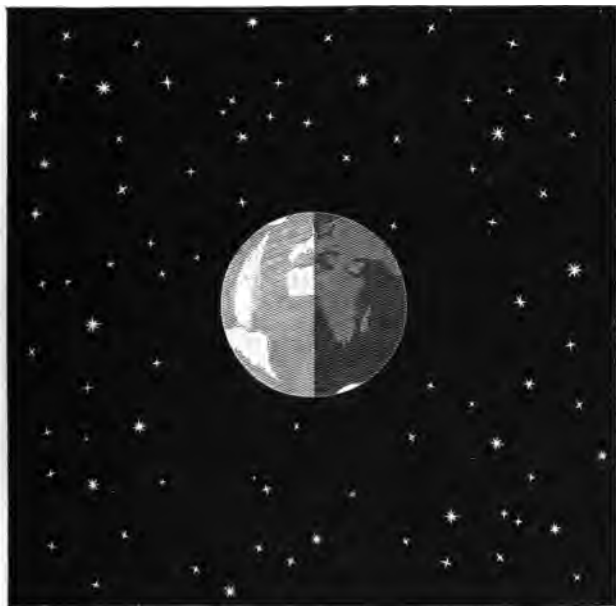


FIG. 13.—The earth in space, during summer in the northern hemisphere.

it runs, becoming less and less hasty in its movements, and finally loses itself in the sea. And what then? The "waters of the earth" lie in great depressions of rocky surface. They want to sink lower, and so cling to the ocean floor, hoping, as it were, that the crust of the earth would break and let them get nearer to the centre of attraction. We are all subject to the dictates

of this same law. Wherever we may be, the point towards which we are attracted is the centre of the earth, and consequently the part of the heavens above us differs according to our position.

Space is boundless—without length, breadth, or depth that we know of. Could we journey through this infinite abyss there would be nothing to tell us whether we were moving “up,” or “down,” or “side-ways,” for these words have no meaning when no top, bottom, or sides exist. In this unlimited universe the earth occupies a point, and, materially speaking, is one of the most unimportant of God’s creations. No foundations are required to support it, for though all our experience tells us that an unsupported ball will fall earthwards, in space there cannot be a “downward” motion.

The seeming motion of the sun across the sky is a phenomenon which cannot be overlooked, though the sight is so familiar that it may not give rise to any inquiry as to the cause producing it. Day after day the “God of Light” rises and puts life into a drowsy earth. When he departs, the flowers droop their heads in sadness, our own vital energy declines, and all nature pines for the return of the bounteous giver of so much gladness. The influence of sunlight is so great and so beneficial that it would have been strange if men had not worshipped our luminary, and paid considerable attention to his motions. In the days when the world was young, observers of the skies had considerable difficulty in thinking out a theory to account for the sun’s daily movement. The Egyptians held that the sun was caught every night on the western horizon and conveyed to the eastern horizon by one of the gods, in

time to rise on the following morning. Though this idea may appear very crude, it is far in advance of a theory held long after by the Greeks. The earth was supposed to be a plane surface surrounded by a river, and in it the sun had a bath every evening, rising "like a giant refreshed" on the following morning. Probably the sinking and subsequent rising of a diver suggested that the sun went through a similar performance. This imaginative idea gave way to the suppositions that the sun passed through a tunnel under the earth, or between roots or pillars, or behind a hill, his temporary absence leaving the earth in the darkness of night.

But the sun is not the only celestial body apparently in constant motion. We have seen in the first chapter that the whole heavens appear to perform a complete rotation from east to west every day. Even after man had discovered that the earth was a sphere, and that the heavens did not repose upon it, but surrounded it on all sides, it was held that the stars existed on a solid firmament which revolved round the earth. Our little globe was then considered to be immovable in the centre of the universe, and the decline of this idea may be said only to have begun with Copernicus, about three centuries ago. This distinguished man demonstrated that the earth is constantly spinning round and round and that the heavens are at rest. The firmament thus appears to move from east to west in a day because the earth rotates from west to east in the same time. Every boy who has been on a merry-go-round at a fair knows that all the objects outside appear to rush past him in a direction opposite to that in which he pursues his mad career. This

apparent motion is a reflection of the boy's real motion, and, by applying similar reasoning to the earth and the heavens, it will easily be understood that, so far as appearances are concerned, it does not matter which is considered to be in rotation. If the merry-go-round were driven so smoothly and uniformly that it was impossible to feel whether it was moving or not, the actual condition of the earth would be realised.

It is not to be wondered at that the theory of the earth's rotation was hotly disputed at the time of Copernicus. Until the fact that the earth and its atmosphere move with absolute uniformity is fully grasped, it is difficult for us to conceive that objects on the earth's equator are being whirled round with a velocity of one thousand miles an hour. At all events, it is much easier to think that the earth is at rest, and the celestial vault is moving round it, than to believe that the reverse is the case. After Copernicus, facts were produced which added to the probability of the earth's rotation. By watching the movements of spots upon the sun, our luminary was shown to have a spinning motion. What was more natural than to argue from analogy that the earth behaves in a similar fashion. At the present time, however, we have neither to rely upon probability nor analogy. Through the ingenuity of a famous French physicist named Foucault, the rotation of the earth can be proved in the following conclusive manner.

When an inanimate object, such as a stone, is set in motion, it goes on moving in the direction in which it was started, unless some disturbing influence deflects it from this path. As an example of this law of motion,

let us consider a vibrating pendulum formed by suspending a weight from a thread, or better, a fine wire. If the wire is clamped properly at the upper end, the pendulum will move to and fro in exactly the same direction as that in which it was started, until it comes to rest. This tendency to preserve the original direction of motion in the case of a simple pendulum can be illustrated by means of an experiment (Fig. 14).

The feet of a gallows-shaped erection are fixed in a circular piece of wood, which turns round on a pin at

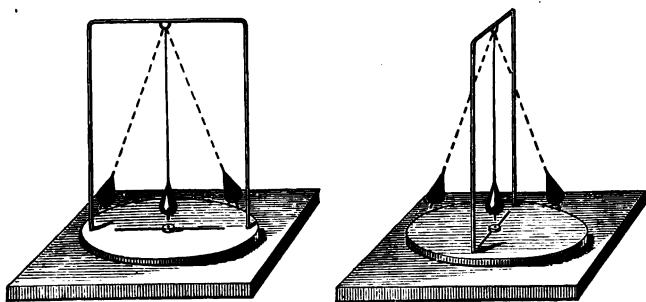


FIG. 14.—Model to show that the thread or fine wire suspending a weight swinging to and fro can be twisted without changing the direction of vibration.

its centre. From the middle of the cross-piece of the gallows hangs a fine wire or thread, at the end of which is a lead weight. Suppose the weight is pulled to one side and let go, so that it vibrates in the direction of the line joining the two uprights. And when this has been done, let the disc be gently and slowly turned round. The pendulum will be found stubbornly to refuse to partake of this motion. It will keep moving to and fro in the original direction, though no longer between the uprights. When the uprights have been rotated through one-quarter of a complete

turn, the pendulum motion will be across the line connecting them. Rotate the uprights half-way round, and the pendulum will again beat between them, though they will have changed sides. At three-quarters of a complete turn the line of movement again cuts straight across that which joins the uprights, and when the circular slab has been rotated through a whole circumference, the conditions are the same as at the beginning of the experiment. It is obvious, then, that a pendulum cannot easily have its

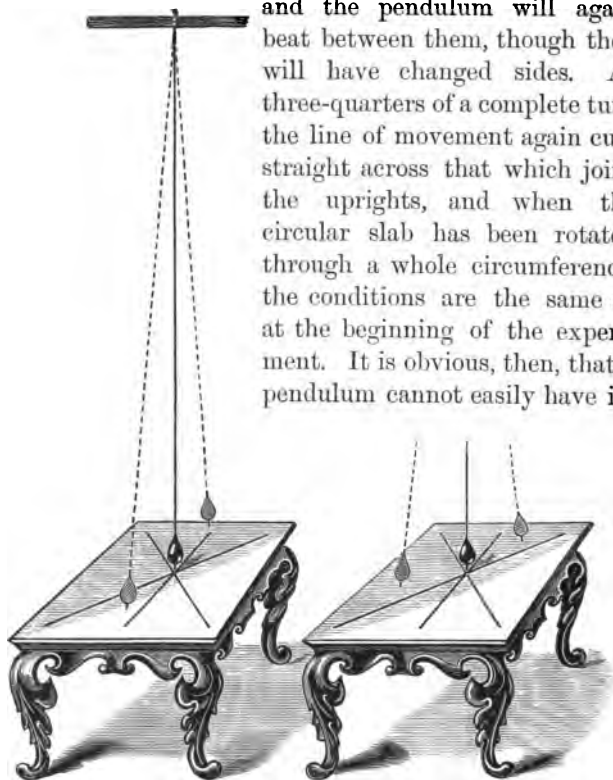


FIG. 15.—The left-hand figure shows a Foucault's pendulum started over a central line on a table in the northern hemisphere; the right-hand figure shows the apparent change after about two hours.

direction of vibration altered. The rotation of the gallows from which the pendulum hangs twists the thread of suspension, but fails to move the pendulum

from its proper path. Resolute and independent of the rotating framework, the weight keeps up its oscillations, behaving as if it wished to demonstrate that it was in no way connected with such a degrading structure as a gallows.

With these facts in mind, it is easy to understand Foucault's experiment for proving the rotation of the earth (Fig. 15). In 1851 this observer suspended a heavy iron ball from the dome of the Paris Pantheon by means of a fine wire about two hundred feet long. The pendulum thus constituted was then pulled out of its position of rest, and tied with a piece of thin string to a fixed pillar. The string was afterwards burnt, and the pendulum began its oscillations in a certain direction. After a time it was found that the direction of motion, with respect to the floor of the Pantheon, had altered. To all appearances it seemed as if the plane in which the pendulum vibrated were slowly moving round in the same direction as that of the hands of a watch laid on the floor. But our experiment has shown us that a heavy moving body cannot easily be turned out of its original path. For this reason it was concluded that the whole of the building was gradually rotating in the opposite direction to that of watch-hands, while the pendulum-bob kept doggedly swinging in the way it was made to go. The experiment has been repeated many times since Foucault's day, and a similar result has always been obtained. The earth's rotation is thus placed beyond the possibility of a doubt.

If a "Foucault's pendulum" could be suspended from a large gallows at the poles, and could be

kept vibrating for a day, it would behave in precisely the same manner as the pendulum of our illustration. In four minutes less than twenty-four hours, the earth would have made a complete rotation under the pendulum, and the line of vibration would appear to turn through 360 degrees at the uniform rate of 15 degrees per hour. If, then, the hourly rate of change is observed, the time taken by the earth to make a complete rotation can be calculated. The case is not so simple away from the poles. Nevertheless, the rotation period calculated from observations of the hourly change in different latitudes is very near the truth, being 23 hours 53 minutes, instead of 23 hours 56 minutes, long. The latter value is found by observations of the heavens.

If a bright star is observed when looking towards the south-east on a very fine night, it will be seen slowly to climb higher and higher in the sky, until it reaches a certain point, and then as gradually to sink towards the western horizon. When at the highest point, the star is due south, and if the interval between the "southings" on two successive nights is observed, it will be found to be 23 hours 56 minutes. This, then, is the length of a star-day—a day measured by the apparent movements of the stars. No matter what stars are observed, the interval between two successive southings is exactly the same. Indeed, from the condition of things such a result is to be expected. The stars surround the earth on all sides. Let us consider them as the eyes of celestial spectators seated in a vast coliseum and watching the motions of our planet. Each star occupies a certain position in the

sky—each spectator has a particular place in the coliseum. Single out one of the members of the throng, upon which the attention can be concentrated, and suppose that, in consequence of the rotation of the earth, he is just coming into view. As the spin goes on, he becomes more and more visible, and eventually is directly in front of us. We are then turned away, and he appears slowly to pass in the opposite direction until he becomes invisible. Fresh faces are seen, but after a time our old friend again appears, and goes through the same apparent movements. There is no difficulty in understanding that it is quite immaterial which individual is selected for observation, if we wish to find the length of a period of rotation. The time is noted at which the favoured one passes in front of the place of observation, and then again noted when he once more occupies the same apparent position. The interval between the two times is the required length.

We do not see the stars throughout the whole period of rotation, but only during a part of it. This may appear strange in the light of the statement that stars exist on all sides of the earth, but the seeming discrepancy between assertion and fact is easily explained. During the day we are turned towards the part of the sky occupied by the sun. The light of our great energiser is diffused by the atmosphere, and the glare produced is so intense that the faint light of the stars cannot pierce it. Extinguish the sun at any moment and the stars in the heavens behind it would be seen shining by their own light, utterly unaffected by the catastrophe that had occurred. Indeed, with

a good telescope, the bright stars can easily be seen even in the daytime.

The sun, like the stars, rises, souths, and sets by reason of the rotation of the earth. It is day when we are turned towards it, night when away from it. Before our luminary appears on the eastern horizon, the light of dawn is seen, and in it the star-beams are gradually lost. For a short time after the sun has set, twilight occurs. From these phenomena, primitive man inferred that the length of the day was independent of the sun. It was thought that the sun did not make the day, but added its light to another source—the source whose emanations produced dawn and twilight, and lit up the earth when the sun was hidden by clouds. In those days it was not known that we live in a sea of air, which surrounds our globe, and therefore the part played by the atmosphere in lighting up the earth was not understood. Rob the earth of its aerial envelope, and as soon as the sun had sunk below our horizon we should be plunged in darkness. But the upper layers of air receive the light of the sun before lower levels; they bend and diffuse it, and so illuminate the earth, before the sun's direct rays strike along the surface. Similarly, in the day, sunlight is diffused or dissipated by innumerable air-particles, enabling us to enjoy light when the source is hidden by clouds. Thus the cause which prevents us seeing the sun on a star-spangled sky is the same as that which increases the length of the day by producing the phenomena of dawn and twilight.

That the earth is in rotation has been sufficiently proved, but nothing has been said as to how this

motion occurs, though it will be inferred, from the description of Foucault's pendulum, that the places nearest the earth's centre—the poles—are also the points of rest. This is indeed the case. The shortest diameter is also the axis about which the earth rotates. A knitting needle run through the centre of an orange from top to bottom exemplifies in reality the imaginary axis which connects the north and south terrestrial poles. There is a reason for this coincidence. Many rocks, such as granite, have the appearance of having once been in a molten condition, indeed, there is little doubt that the whole earth at one time consisted of a mass of hot, liquid rock. As the mass cooled, a solid crust was formed round it, and in time became fit for habitation. Volcanoes and earthquakes, and observations in mines and bore-holes, clearly show that the earth's interior is still very hot, but as to whether it is solid or liquid is not definitely known. With this geological information we are able to proceed to inquire into the cause of the earth's polar compression.

Arguing from abstract reasoning, it would be concluded that the earth is a perfect sphere. This is also the form which would be assumed by a mass of molten material obeying the law of universal attraction. The tendency is always towards a "perfect figure," using the words in a geometrical sense. But the earth is in rotation; it always must have been spinning round and round, and mathematicians can prove that a mass of fluid possessing such a motion must become compressed where the whirling motion is least. But the untrained mind does not readily accept the conclusions of mathematicians. Fortunate

it is, then, that the flattening of a sphere by rotation can be proved by experiment. A drop of oil, suspended in a liquid with which it does not mix, becomes a perfect globe. Cause the drop to rotate and it is at once flattened at the extremities of the axis of spin. The effect of rotation is also exhibited by rapidly whirling a hoop of thin steel about a diameter (Fig. 16). Before being set in motion, the hoop is circular, but as it spins round and round it becomes compressed where the whirling motion is least, and bulged out where it is

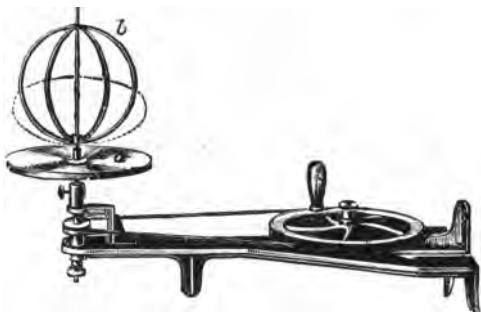


FIG. 16.—To illustrate the flattening of a flexible hoop by rotation.

greatest. Thus, the axis of rotation always coincides with the shortest diameter in our experiments. It is fair to conclude, therefore, that the spinning of the earth in bygone days caused the flattening at the poles and the bulging at the equator. We have seen that the more rapid the rotation, the greater is the effect produced. This also applies to celestial bodies. The sun, a stupendous mass of gas and liquefied matter, is spinning, but it only turns round once while the earth is rotating twenty-five times. In consequence of this, the outline of the sun appears to be perfectly circular—

there is no appreciable difference between the polar and equatorial diameters. On the other hand, two brothers of the earth, Jupiter and Saturn, show very conspicuous polar compressions, owing doubtless to the fact that they are both in rapid rotation, for each performs a complete spin in about ten hours. There is thus an intimate relation between the velocity of rotation and the variation from the spherical form. It is for this reason that the mathematician would conclude that since the earth is in rotation, it must deviate from circular perfection, even if the true shape had not been found by observation. A poet has written—

The very law that moulds a tear,
And bids it trickle from its source,
That law preserves the earth a sphere,
And guides the planets in their course.

And he is right in so far as he expresses the fact that the law of gravitation tends to make all aggregations of matter assume the spherical form. Gravitation is tending all the while to pull the particles into a spherical shape. But other influences tend to divert the particles from their proper position, and the result is that a tear, like a dewdrop or a raindrop, is never truly spherical, and that the earth and all other bodies in rotation vary considerably from the poetical conception.

SYNOPSIS OF CHAPTER II

The form of the earth.—Proofs of the earth's globular form : (1) The shadow of the earth, into which the moon passes during an eclipse, has a circular outline ; (2) the dip of the horizon is everywhere the same ; (3) the altitudes of stars

regularly increase in travelling to higher latitudes ; and (4) the times at which the sun and stars are due south are different at different places.

The earth spins or rotates like a top, taking 23 hours 56 minutes to perform one rotation. The axis of rotation coincides with the shortest diameter, and the poles are at its extremities.

The apparent motion of the heavens from east to west, in consequence of which celestial bodies rise, south, and set, is a reflection of the earth's real motion in an opposite direction.

The reason why stars are invisible during the day, except a telescope is employed, is that the glare of sunlight in the earth's atmosphere overpowers their faint rays.

Dawn and twilight are caused by the sun illuminating the upper regions of our atmosphere. The phenomena would not occur if the earth were without an atmosphere and would last longer if the atmosphere were increased in height.

The earth is a cooling globe.—It was once a ball of molten matter ; at the present time the interior is hot ; in the distant future it will have cooled down to the condition of the moon.

The effects of rotation upon a ball of melted rock, such as that in which the earth at one time existed, would be to cause polar compression and equatorial bulging. The amount of compression exhibited by a solid celestial body furnishes a means of calculating the period of rotation at the time of solidification.

Polar compression and rotational velocity are intimately connected. If the latter is increased the former is increased also. The sun is an example of a body having a low velocity of rotation. Saturn and Jupiter exhibit effects of high velocity.

CHAPTER III

THE SIZE AND MASS OF THE EARTH

IN the previous chapter a general idea has been given of the figure of the earth, and we have now to show how the exact size and shape have been determined. But, before going into the subject, it is necessary to have a clear idea as to the method of measuring angles. To say that an angle is so many yards or feet wide is, of course, meaningless; it is just as absurd as expressing the time of day in miles. We use inches, feet, yards, and miles to measure linear dimensions; the flow of time is measured in seconds, minutes, and hours; and to properly express the sizes of angles, certain definite units of reference must be employed. The first thing necessary, then, is to determine the unit employed in angular measurement.

If circles of any size are drawn, and the circumference of each is divided into, say, a dozen parts, the angle between two lines drawn from two adjoining parts to the centre always remains the same. In a similar manner, when the circumference is divided into 360 parts, the angle between two lines drawn from two adjoining parts is constant, whatever the size of the circle. This angle is termed a "degree." We

can illustrate the principle of angular measurement by means of a watch (Fig. 17). The dial of a watch or clock has sixty points marked upon it, each representing one minute of time. On a small watch the points are rather close together ; on the dial of a large clock

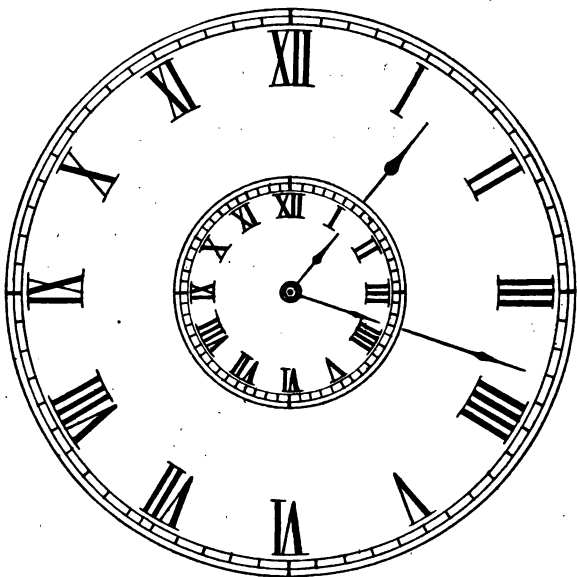


FIG. 17.—To show that the angle contained between two lines does not depend upon the size of a circle.

they are very clearly separated. But whether the minutes on the dial of the clock at Westminster are taken, or those of the smallest ladies' timekeeper, two lines drawn from two successive points to the centre include precisely the same angle in each case. The minute hand of a clock or watch moves through 360 degrees in going completely round the face. In pass-

ing from XII. to VI. the hand moves through 180 degrees, and from XII. to III. it moves through 90 degrees. Hence it is easily calculated that, in moving from one minute to the next, the hand travels through 6 degrees. Degrees of angular measurement are divided into sixty equal parts, known as minutes, and these in turn are divided into sixty equal parts termed seconds. Degrees ($^{\circ}$), minutes ($'$), and seconds ($''$) of arc must not, of course, be confused with hours (h.), minutes (m.), and seconds (s.) of time. With this preliminary information, the methods of determining the exact size and shape of the earth can be understood.

In the first place, it is evident that if we have only a portion, or an "arc," of the circumference of a circle, and we know the angle between two lines drawn from the ends of the arc to the centre, we can calculate the length of the complete circumference. Thus, suppose a certain arc measured two inches, and that the lines from the ends of the arc were inclined to each other at an angle of 12 degrees, then the length of the circumference would be thirty times two inches, that is, 60 inches, for 12 degrees represent one-thirtieth of the whole 360 degrees. Applying similar reasoning to the case of the earth, it will be seen that if we know the exact length of a comparatively small part of the circumference, and the angle between two lines drawn from the centre of the earth to the ends of the arc, the distance round the earth can be found.

The first thing to be done, then, is to accurately determine the length of a line a few hundreds of miles long. A more or less level plain is chosen. To it are conveyed a half dozen bars, each about ten feet long,

and constructed in such a manner that they remain of the same length under all conditions of the atmosphere. These are used to measure the length of a line along the plain. It must not be thought for an instant that the bars are simply laid end to end in making this measurement. Most elaborate precautions are used to ensure accuracy. Near the ends of each bar is a small mark, and to connect two bars, one of a pair of microscopes is sighted on one of the marks, while its companion is sighted on the mark at an end of the following bar. Before doing this, however, the bars are made absolutely horizontal by means of spirit levels. By accurately levelling and optically connecting six bars in this fashion, a line nearly seven miles long has been measured on Salisbury Plain with extreme precision. This forms what is known as the "base-line" of the operations. The instruments used in its measurement are now set aside, and others of quite a different kind take their place.

Surveyors go to one end of the base line with a theodolite, which is an instrument for measuring angles. They fix the theodolite exactly over the point which marks the end, and then sight it upon a conspicuous object in the distance, such as a church tower. The "bearing" of the tower with respect to the direction of the base-line is thus obtained. Observations of the same kind are afterwards made at the other extremity of the line, and, from the two bearings and the length of the line, the distance of the tower from either extremity can be calculated. The tower and the ends of the base-line lie at the corners of an enormous triangle. By measuring the length of the base of the triangle, and also the angles which it makes with each side,

the distance of the opposite angle has been found (Fig. 18).

When one side and two angles near it are known in any triangle, the exact size of the figure can always be calculated. A number of triangles are measured from the base-line, each having in the distant corner some conspicuous object upon which the surveying instruments are easily sighted (Fig. 19). After this has been done, a calculated side of one of the large triangles is

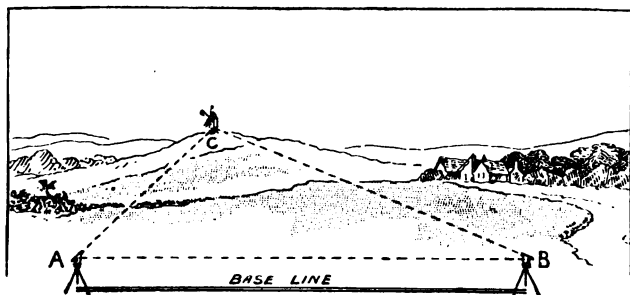


FIG. 18.—By measuring the length of the line AB, and determining the angles at A and B by means of a theodolite, the distance of the point C can be calculated.

used as a base. Pointings are made from the two ends of this line to another object, and the distance of the object is calculated as before. A new triangle is thus constructed, the sides of which serve as bases for others, and step by step the scheme goes on until a large tract of country, extending more or less in a north and south direction, is covered with a network of triangles. The sizes of the triangles being known, the distance between any two points in the tract of country covered by them can be estimated.

Now, to determine the size of the earth, we first

require to know the exact distance between two points in the same north and south line or meridian. Such a line represents a circumference of the earth, and if we accurately know the length of a part of it, and know what fraction it is of the whole, we can easily find the distance round the earth.

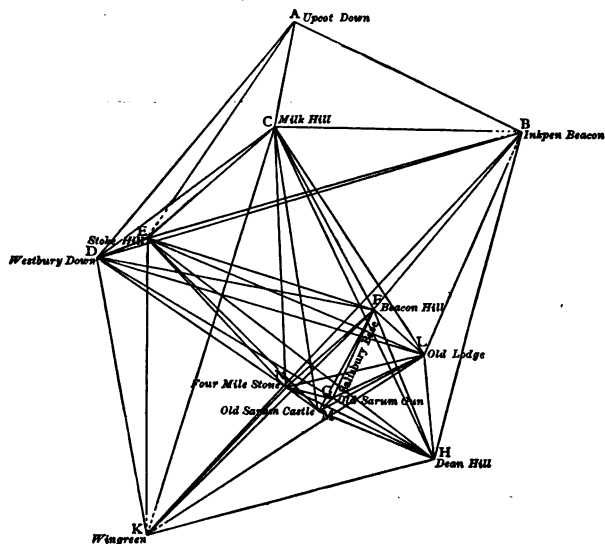


FIG. 19.—A few of the triangles measured near the base-line on Salisbury Plain by the British Ordnance Survey.

The work of the surveyor enables the distance between two points on the same meridian to be estimated. It remains to find what fraction this is of the entire circumference. This may appear to be a rather difficult problem. The surveyor cannot travel with his elaborate equipment of delicate instruments and measure up tracts of sea and land until he has

circled the globe with a band of triangles. But even if he could do so, his labour would be quite unnecessary. In fact, the work of the surveyor terminates when he has measured up a tract of country.

The astronomer then commences a new kind of observation. His work is to accurately determine the latitudes of the ends of the north and south line.

Latitude, as is generally known, is angular distance from the earth's equator.

Imagine a pair of compasses, each leg of which is long enough to reach from the

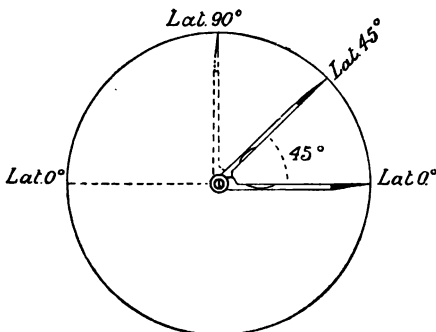


FIG. 20.—Latitude is angular distance from the equator.

centre of the earth to the surface. If one leg is kept pointed to the equator, and the compasses are gradually opened while the end of the other leg traces out a north and south line, then the angle between the two legs at any time is the latitude of the place to which the movable leg is directed (Fig. 20). In opening the legs until they stand at right angles to one another, 90 degrees of latitude are passed over. The movable leg then points to the pole.

If we knew the distance along the surface of the earth from the equator to either pole, the circumference could be found at once. For since 90 degrees are one-fourth of 360 degrees, the known distance is one-fourth of the unknown circumference. By

similar reasoning, it will be seen that when the astronomers have accurately determined the difference

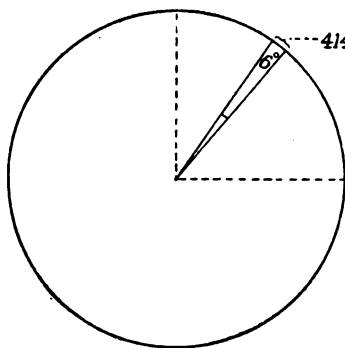


FIG. 21.—As 6° is to 360° , so is 414 miles to the circumference of the earth.

of latitude of two points on the same meridian, and ascertained their distance apart, the earth's circumference can be computed. For, suppose the distance, according to the triangulation of the country, is 414 miles, and suppose the astro-

nomers find that this corresponds to a difference of 6 degrees of latitude. Six degrees are one-sixtieth of 360 degrees, hence 414 miles are one-sixtieth of the whole distance round the earth. Clearly, then, the circumference is sixty times 414 miles, that is, 24,840 miles, and this is not far from the true value (Fig. 21).

There is a definite relation between the circumference, or the distance round a circle, and the diameter, or the greatest distance across. Every circular circumference is a little more than three times longer than the diameter; to be more accurate, it is nearly three and one-seventh times longer. A halfpenny is exactly 1 inch in diameter; its circumference is therefore $3\frac{1}{7}$ inches long. A bicycle wheel 35 inches high has a tyre 110 inches long, in fact, the rule holds good for circles of any size. Since, then, the circumference of the earth is 24,840 miles, the distance through

the earth—the diameter—is rather less than one-third this length. It is 24,840 divided by $3\frac{1}{2}$, that is, 7904 miles.

Base lines have been measured in very many parts of the earth, in equatorial and polar regions, and in middle latitudes, and from them different tracts of country have been surveyed, and the difference of latitude between two points at a known distance apart has been astronomically determined. The results show that the length of a degree of latitude, that is, the distance which it is necessary to travel along a meridian to cause a change of one degree in the altitude of the Pole-Star, is three-quarters of a mile less at the equator than near the poles, and progressively increases from the former to the latter latitude. It therefore follows that if the circumference of the earth is calculated from operations near the equator, the result will be much less than if operations in our own latitude or near the poles are used for the same purpose. In other words, the polar regions have the curvature of a globe with a larger radius than equatorial regions. But the larger the globe the less is the curvature of its surface, hence the earth is a sphere flattened at the poles—an oblate spheroid.

It would hardly be thought that the swinging to and fro of a pendulum affords the best means of determining the exact shape of the earth, yet such is the case. Why does a simple pendulum, such as a bullet suspended by a thread, swing at all? When the pendulum is pulled aside out of its normal position and then released, it does not merely fall to its former point of rest, but swings past this point to a short distance on the other side, then back again through the original

position and so on, each time rising less than before, until it once more comes to rest. These oscillations are produced by the attraction of the earth, and the strength of the pull depends upon the distance of the pendulum from the earth's centre.

If the earth were at rest, and if it resembled a billiard ball in structure and shape, the same pendulum would beat at the same rate, if set in motion at any place on the surface. But observations show that this is not the case. Journey with a pendulum from the equator towards the poles, and a slight but definite quickening of the rate will be manifested, becoming more and more evident as the distance from the starting point is increased. No matter what the length may be, the pendulum beats faster and faster as the poles of the earth are approached. The increased speed is such that a pendulum clock which has been made to keep absolutely accurate time at the equator, gains three and a half minutes every day when taken into polar regions. The obvious conclusion from this behaviour is that the attraction exerted by the earth upon a pendulum is greater near the poles than at the equator. And it is greater partly because the pendulum is then nearer the centre of the earth—nearer the point at which all the power of attraction can be considered to be concentrated. Since this is the case, all parts of the earth's surface are not at an equal distance from the centre, in other words, the earth is not a perfect globe; it is a globe slightly flattened at the polar regions.

The distance through the earth from pole to pole is thus less than that which separates two opposite points on the equator. As a matter of fact,

the difference is nearly twenty-seven miles, for the distance through the earth at the poles is 7900 miles, while the diameter at the equator is nearly 7927 miles in length. On a globe 2 feet in diameter this difference would be represented by a little less than one-twelfth of an inch. To compare the earth with an orange leads, therefore, to a misconception as to the amount of polar compression, for if the earth were accurately represented by a ball of such a size, the departure from the globular form would be quite imperceptible.

The diameter of the earth having been found, the extent of the surface can be easily calculated. It proves to be rather more than 197 millions of square miles. Of this vast area, the land surface consists of about 52 millions of miles, or 33,280 millions of acres.

We have now come to a most important point, namely, the determination of the mass of the earth. But before going further, it is necessary to clearly define the meaning of mass. Suppose for a moment that we could fly away into a region of space far removed from the earth or any other body, taking with us a ball of lead and a ball of cork, and placing them in this infinite ocean. The balls would remain for a time at the points in which they were placed, for, like other inanimate objects, they are quite unable to set themselves in motion. Now let us suppose that we try to move the balls. It would be found that in order to give them the same velocity, different amounts of force would have to be employed; in other words, the lead ball would be harder to move than the cork one. In fact this objection to change—this inertia, as it is called—differs according to the quan-

tity of matter in a body, hence the forces required to give the two balls the same velocity represent respectively the quantities of matter in them. The word mass is used to express quantity of matter, so we see that a body's conservatism as regards change of position varies according to its mass, or, to express the point in a definite manner, the mass of a body is measured by its inertia.

We will pass to the consideration of the action of one mass upon another. Sir Isaac Newton showed that every particle of matter in the universe attracts every other particle. It is in accordance with this law—the law of gravitation—that an unsupported stone falls to the ground, and that the moon preserves her monthly journey round our earth.

The strength of the attraction between any two masses—the force with which they tend to approach one another, is variable. In the first place it differs according to the masses under consideration, being directly proportional to their product. Double the number which results from multiplying one mass by the other, and the force of attraction is doubled; treble it, and the force is three times as great. The force also depends upon the distance separating the centres of the attracting masses: the greater the distance, the less intense is the attraction. The rate of diminution follows what is known as “the law of inverse squares.” At twice the distance, the force has only one-quarter its original value, at treble the distance it has sunk to one-ninth, at four times the distance to one-sixteenth, and so on for any other distance.

Now suppose two large masses are placed at an

equal distance from a smaller one. If we can measure the force with which the third body is attracted in each case, we can compare the masses of the two others. Should one exert a force two thousand times greater than the other, its mass would be two thousand times greater. And even if the distance separating the third body from the larger bodies were not equal, it is still possible to compare the masses by measuring the force of attraction, and then placing the results on an equal footing by the application of the law previously stated. This being understood, the theory of an experiment carried out by Cavendish in 1798, and since repeated with far more delicate apparatus by different observers, will be easily followed.

It is required to compare the attractions which the earth and a body of known mass respectively exert upon a third object. A small ball is taken. Its weight is a measure of the attraction at the earth's surface, that is, at a distance of about 4000 miles from the centre. The ball is arranged so that the slightest movement from a certain position can be detected. A heavy lead ball is brought near it and attracts it. The change produced is measured, and also the distance separating the centre of the two balls. From the former the force of attraction exerted by the lead ball is calculated, and by applying "the law of inverse squares" an estimation can be made of what the attraction would be if the balls were separated by a distance of 4000 miles. We then have the attractions of the earth and the lead ball on an equal footing. A ball 41 million feet in diameter is being compared with one only a foot across. It is like comparing the strength of an elephant with that of a

minute insect. To be fair, let us imagine that the lead ball is as large as the earth and then make the comparison. When this has been done, it will be found that the imaginary ball of lead would have about twice the pulling power of the earth. Hence a ball of lead as large as the earth has a mass double that of the earth itself.

In practical science it is usual to use water as the standard of comparison and to express by the word density or, more accurately, specific gravity, the ratio of the weight of a substance to the weight of an equal volume of water. Bulk for bulk, lead weighs 11·2 times as much as water; this number, therefore, represents the density of lead. And since the earth, as a whole, has half the mass of a ball of lead of the same size, its density is half that of lead, that is 5·6; in other words, the earth's mass is 5·6 times greater than the mass of a globe of water of the same size. Now a cubic mile of water weighs 410 million tons. There are 260,000 millions of cubic miles in the earth, hence, if our globe consisted of water, its weight in tons would be 410 millions multiplied by 260,000 millions. But since the earth is heavier than water, the result obtained has to be multiplied by 5·6 to get the proper value. It is impossible to grasp the significance of the string of figures thus found. Here it is, 6,000,000,000,000,000,000,000 tons. Or, expressed in words, six thousand trillion tons.

The working of this sum must be considered more as a feat of arithmetical gymnastics than anything else. It is not at all necessary to know the earth's weight in tons for astronomical purposes; indeed the very word weight used in such a sense is a misnomer. Weight is simply

a measure of the attraction of the earth at the surface, and the foregoing incomprehensible number represents the total result which would be obtained if every cubic foot of rock could be brought to the surface and weighed. In problems of celestial mechanics, however, all that is required is to know the amount of pull due to the earth's mass in comparison with that exerted by other bodies.

SYNOPSIS OF CHAPTER III

The measurement of angles.—The radius of a circle passes over 360 degrees (°) in making one revolution. Each degree contains 60 minutes (′), and each minute 60 seconds (″).

Determination of the size of the earth.—The operations involved are: (1) the measurement of a base line; (2) the triangulation of a tract of country from the base; (3) the determination of the difference of latitude between two points at a known distance apart.

The earth's shape is that of a globe slightly compressed at the poles. This is proved by (1) the progressive increase in the lengths of degrees of latitude from the equator to the poles; (2) the increased rate of a pendulum taken to higher latitudes.

The earth's exact size—

Polar diameter.	.	.	.	.	7900 miles
Equatorial diameter	.	.	.	.	7927 "
Mean "	.	.	.	.	7018 "
Surface	.	.	.	197,000,000 sq.	"
Bulk or volume	.	.	.	260,000,000,000 cub.	"

The earth's density.—The pull of a lead ball of known mass and size is compared with the pull of the earth. The latter is calculated to pull with half the force of a lead ball of the same size, and its mass is, therefore, half what it would be if composed of lead. But since density is proportional to mass, the earth's density is half that of lead, that is about $5\frac{1}{2}$.

A *celestial meridian* is a great circle passing through the zenith and nadir of a place and through the celestial poles.

The *meridian* of a place on the earth is a great circle passing through that place and the terrestrial poles.

The *longitude* of a place is the angular distance between the meridian of that place and a conventional meridian; *latitude* is angular distance north or south of the equator.

CHAPTER IV

WANDERING STARS

“AND God said, Let there be lights in the firmament of the heaven to divide the day from the night; and let them be for signs, and for seasons, and for days and years.” These are the words of the writer of Genesis, and they reflect the mode of thought common in his day. The motion of the sun across the sky forced itself upon the attention of mankind from time immemorial. In the early morning the orb of heaven appears upon the eastern horizon; he crosses the sky in a majestic sweep, and disappears in the evening. From the time of rising, the ruler of day climbs the sky. It is midday when the highest point is reached, and shadows thrown by sunlight then have their shortest length. The farm-labourer working in the fields observes the fact, and forthwith departs to his midday meal. As the sun slowly sinks towards the west, the shadows increase in length, and finally the twilight shades merge into the darkness of night. These variations are so obvious that they cannot escape notice; hence there is no difficulty in understanding that men ignorant of the cause of the apparent motion of the heavens considered that one of

the chief functions of the sun was to let them know how the time passed.

The apparent daily motion of the sun is known to all, but there is an apparent yearly motion which is only detected by the observant. In the evening, when the sun has sunk "to shine on other climes," and night has come on, certain groups of stars or constellations will be seen above the western horizon, other groups will be southing, and still other groups will be found in the east. Watch the sky at the same time every night, and in a few days the stars which were seen just above the western horizon at the end of twilight appear on the horizon; those that were due south appear nearer the west, and those that were on the eastern horizon are seen above it. In the course of a few weeks the stars which were seen above the western horizon just after sunset will be invisible; those which were on the eastern horizon will be high above it, and other stars will have taken their place. In about six months after the first observation, stars which were on the eastern horizon will appear on the western horizon at the same time, and in a year the sky presents the same appearance as formerly. Leaving for the present the cause of these changes, let us inquire how they were used by ancient peoples to measure time.

Imagine for a moment that we had to look heavenward "for seasons, for days and years," instead of depending upon such mundane contrivances as clocks and calendars. A sun-dial enables us to find the time of day; the passage of the stars across the sky serves the same purpose at night. For the regulation of our seasons let us look to the stars in

the midnight sky. In the winter months the most conspicuous constellation to be seen when looking towards the south is that of Orion. Just when the days are beginning to lengthen, the giant appears due south at midnight. As spring approaches, Orion moves westward from his proud position, and when it has arrived, he is invisible at midnight, and the Virgin has taken his place. This is the time of year when, to quote Tennyson,

The shining daffodil dies, and the charioteer
And starry Gemini hang like glorious crowns
Over Orion's grave, low down in the west.

The appearance of the Virgin in the midnight sky could serve as an indication that sowing time had come. At the time when the days are longest, Hercules occupies the highest position at midnight. The autumn—the time for reaping—is announced by the appearance of Andromeda in the midnight sky, with Orion in the east, and winter again sees the conspicuous belt in its former place. Thus the heavens serve to mark the succession of the seasons, and it is for this reason that the movements of celestial bodies have been studied throughout historic time. We still measure time by the movements of the sun and stars. Our day is the average interval between two successive southings of the sun; our year is determined by the relation between the aspect of the heavens and the seasons. But the poetical idea that the heavenly bodies are kept in motion for man's especial benefit has been discarded as civilisation has advanced.

This is a necessary consequence of the development

of the human intellect. As Lytton says: "Man is arrogant in proportion to his ignorance. Man's natural tendency is to egotism. Man in his infancy of knowledge thinks that all creation was formed for him. For several ages he saw in the countless worlds that sparkle through space, like the bubbles of a shoreless ocean, only the petty candles, the household torches that Providence had been pleased to light but to make the night more agreeable to man. Astronomy has corrected this delusion of human vanity. And man now reluctantly confesses that the stars are worlds, larger and more glorious than his own,—that the earth on which he crawls is a scarce visible speck on the vast chart of creation."

Near the equator, where twilight only lasts for a very short time, the stars become visible almost as soon as the sun has disappeared below the horizon. The constellations near the sun at sunset are therefore more easily distinguished than in our latitudes. If they are noted night after night, the apparent yearly path of the sun among the stars will be found. The accumulation of such observations showed early astronomers that the sun was always accompanied by a particular star-group at a particular time of year; in other words, our luminary does not appear to pass through one set of stars in one year and another set in the following year, but keeps to a fixed track, known to astronomers as the "ecliptic."

At midday the sun shines straight down on our part of the earth; at midnight we are turned to the opposite region of the sky. Evidently, then, the stars due south at midnight at any time of the year are those

upon which the sun will be projected six months later. The part of the ecliptic which reaches its highest point at midnight in midsummer is the part occupied by the sun on the shortest day; that behind the sun at the commencement of spring is due south at midnight in the beginning of autumn. This being so, it is not difficult to understand how the ancients were able to state the parts of the ecliptic occupied by the sun at different times of the year. Roughly speaking, the ecliptic stars southing at midnight were observed, and then a six months' correction was applied to find the sun's place at the time of observation.

Extending to a short distance on both sides of the ecliptic line is a band known as the "zodiac." The "zodiacal constellations" are, as the term implies, the constellations of the zodiac — the groups of stars through which the sun passes in its annual journey. In the dawn of astronomy, distinguishing names were given to portions of the zodiac occupied by the sun at different times of the year, and later days saw the band divided into twelve equal parts or "signs," through each of which the sun passed in a month (see "Frontispiece"). The names of the constellations which happen to lie along the zodiac are, in old English doggerel:—

The Ram, the Bull, the Heavenly Twins,
And next the Crab, the Lion shines,
The Virgin and the Scales;
The Scorpion, Archer, and He-Goat,
The Man that bears the watering-pot
And Fish with glittering tails.

The origin of these names has been a matter of much speculation. As the ancients watched the re-

lation of the sun to the stars for purposes of husbandry, it is reasonable to suppose that the names of the constellations traversed by the sun should be connected with agricultural operations, and terrestrial phenomena brought about by the succession of the seasons. In the words of the popular French astronomer, Camille Flammarion, "The Ethiopian, at Thebes, would call the stars that by their rising at a particular time indicated the inundation of the Nile, Aquarius or the Waterer; those beneath which it was necessary to put the plough to the earth, the Bull stars. The Lion stars would be those at the appearance of which this formidable animal, driven from the deserts by thirst, showed himself on the borders of the river. Those of the Ear of Corn or the Virgin of harvest, stars beneath which the harvest was to be gathered in; and the sign of the Goat that in which the sun was when these animals were born." . . . "Among the Jews there seems to be some remarkable connection between their patriarchs and these signs, though the history of that connection may not well be made out. The twelve signs are mentioned as being worshipped, along with the sun and moon, in the book of Kings. But what is more remarkable is the dream of Joseph, in which the sun and moon and the other eleven stars worshipped him, coupled with the various designations or descriptions given to each son in the blessing of Jacob. In Reuben we have the man who is said to be 'unstable as water,' in which we may recognise Aquarius. In Simeon and Levi, 'the brethren,' we have the Twins. Judah is the 'Lion.' Zebulun, 'that dwells at the haven of the sea,' represents Fishes. Issachar is the Bull, or 'strong ass

couching down between two burdens.' Dan, 'the serpent by the way, the adder in the path,' represents the Scorpion. Gad is the Ram, the leader to a troop of sheep. Asher the Balance, as the weigher of bread. Naphtali, 'the hind let loose,' is the Capricorn. Joseph, the Archer, whose bow abode in strength. Benjamin, the Crab, changing from morning to evening, and Dinah, the only daughter, represents the Virgin.

"There is doubtless something far-fetched in some of these comparisons, but when we consider the care with which the number twelve was retained, and that the four chief tribes carried on their sacred standards these very signs—namely, Judah a lion, Reuben a man, Ephraim a bull, and Dan a scorpion,—and notice the numerous traces of astronomical culture in the Jewish ceremonies,—the seven lights of the candlestick, the twelve stones of the High Priest, the feasts at the two equinoxes, the ceremonies connected with a ram and a bull, we cannot doubt that there is something more than chance in the matter, but rather conclude that we have an example of the process by which, in the hands of the Egyptians themselves, astronomical representations became at last actually deified." But though the subject of the zodiac is most interesting, more space cannot be devoted to it here.

The man who discovers for himself the apparent annual motion of the sun among the stars is an astronomer: he must possess the excellent faculty of intellectual observation and not merely the ability to see. In consequence of this motion a yearly variation occurs which affects our creature comforts and which,

therefore, does not require any great mental effort to appreciate it. We refer to the "high" sun of summer and "low" sun of winter.

On the shortest day of the year, if the sun happens to be visible from rising to setting, he will appear to describe a very small arc in the sky. Even at noon the orb of heaven is only a short distance above the horizon, and usually is so diminished in power that we are able to look upon his face with impunity. But from midwinter our source of light and heat begins to revive. Every day he rises earlier and sets later, and is higher at noon than on the previous day. The arcs traversed increase until, when spring awakens, the day is of the same length as the night, and the sun describes a semicircle above the horizon and a semicircle below it. The increase goes on up to midsummer. Towards the end of the "merry month of June" the highest noonday point is reached, and, as if undecided as to future action, the sun appears to travel along the same path for two or three days. When this occurs, the summer solstice has come, the word "solstice" signifying that the sun stands still, instead of continuing his motion towards the north (Fig. 22).

On midsummer day the sun is seen in his greatest elevation; to us in England he is almost, but not quite, overhead at mid-day. This fact needs emphasising, for the sun is commonly said to be directly overhead in the summer. After the summer solstice our light-god takes a downward course. Day by day his noonday height diminishes, and his time above the horizon is decreased. Autumn is reached, and the day again becomes equal to the night.

Through this stage he passes downward, and regains his lowest point in the sky on midwinter day.

The shadows of sun-lit objects decrease in length from dawn to noon and then increase to twilight, for they depend simply upon the height of the sun above the horizon. In a similar manner, noonday shadows decrease in length from the winter to the summer solstice, and then increase back to midwinter. This variation can be used to indicate the time of year, just as the daily change may be employed to mark the time of day.

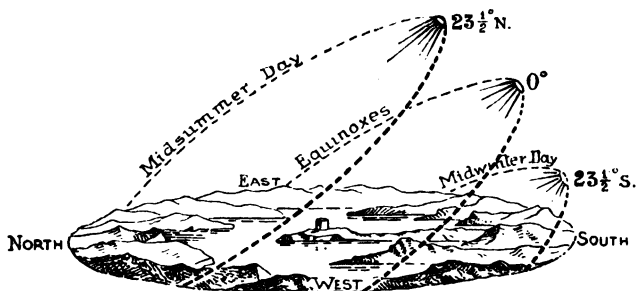


FIG. 22.—To show the apparent paths described by the sun at the solstices and equinoxes, to an observer in the latitude of London.

It has been already pointed out that the altitude of the pole of the heavens above the horizon is equal to the latitude of a place, and that the celestial equator is 90° from each pole. From this it follows that the celestial equator has a fixed height above the horizon of a place. If we imagine that a luminous line had been drawn on the sky in the place of this equator, it would be seen to stretch round from the east point of the horizon to the west, reaching its greatest height in the south. In London, the south point of the

equator has an altitude of $38\frac{1}{2}^{\circ}$. Astronomers measure the distance of celestial bodies from the equator and call them north and south "declinations." Now suppose we find the position of the celestial equator at night by means of the "ever-fixed pole," and fix a pair of compasses so that one of the legs points to it, then in the day we shall be able to determine the sun's position with respect to the equator by pointing the other leg to him. Measures made on this principle show that the sun only travels along the equator at the equinoxes. At the summer solstice the angle between the equator and the noonday sun is $23\frac{1}{2}^{\circ}$. Our luminary is then $23\frac{1}{2}^{\circ}$ north of the equator, and at the winter solstice he is $23\frac{1}{2}^{\circ}$ south of it.

That the sun rises in the east and sets in the west is devoutly believed in by the majority of people. Like many other beliefs, however, it is not based upon fact. Twice a year only, at the equinoxes, that is, at the times when the days and nights are equal, does the sun rise at the eastern point of the horizon and set at the western point. If we should be fortunate enough to see the sun rise on the shortest day of the year, he will be found to come above the horizon near the south-east point. From mid-winter to mid-summer—as the sun is daily soaring higher and higher in the sky—his positions of rising and setting move northwards also. When the sun rises due east and sets due west, spring commences. As we pass from spring to summer—from 20th March to 20th June—the sun rises and sets farther and farther north, and on the latter date appears above the horizon near the north-east point and sinks below it near the north-west. After this the positions of rising and setting

move southwards, are due east and west at the commencement of autumn (23rd September) and reach their south-east and south-west positions with the winter solstice on 21st December. We can sum up all these seasonal changes of the sun's apparent position with regard to our horizon by saying the arcs described by the sun increase in size from the winter to the summer solstice, and their ends, which mark the points of rising and setting, move northwards in the same time; from midsummer to midwinter the case is reversed.

If we could see the stars with the sun during the day throughout a whole year, the position of the line of travel—the ecliptic—could be easily and accurately determined. But though this cannot conveniently be done in the case of the sun, the observation is easy in the case of the moon—"the lesser light made to rule the night." We see the moon associated with and at the same time as the stars, and the most casual observer has learned that she moves among them. To-night she appears to be near certain stars, to-morrow she is to the east of this position, the next day farther east, and in twenty-seven days eight hours "bright Luna" will occupy her former position, having travelled eastwards completely round the sky.

In all probability, the apparent path of the moon was known before that of the sun had been indirectly observed. Be this as it may, when the two paths had been determined they would be found to follow very nearly the same course around the sky. In other words, the sun in his annual journey and the moon in her monthly journey keep in very nearly the same track. The discovery of this important fact is lost in the

remotest antiquity. It doubly concentrated attention upon the zodiac. By dividing the whole circle into twelve equal parts or signs, the monthly travel of the sun was roughly estimated. This division was adopted by the Chaldeans, and is the one now used. Other people recognised also twelve signs of the zodiac, but they employed a division based upon the moon's motion. The moon runs her course in about twenty-eight days. The zodiac was therefore divided into twenty-eight parts or "mansions of the sky," in each of which the moon remains twenty-four hours.

The sun had set. Men witnessed with emotion his disappearance below their world. To them he was dead, but with hopeful feelings they looked forward to the morrow, when the god of day would rise again from his tomb. And, in the twilight, a bright star blazed out in the west, as if to bid the world be of good cheer. For a few hours the brilliant gem of heaven buoyed up the hopes and calmed the fears of mankind, and, when it had set, the whole starry host blazed forth a testimony that the earth had not been forsaken. Such were the sentiments which celestial appearances brought to the minds of the human race in the beginning of the world, as the Evening Star—

the star
Of Hesperus, whose office is to bring
Twilight upon the earth—

was watched (Fig. 23).

If the Evening Star, which we call Venus, is observed for some weeks, several facts will be found concerning it—facts which must have troubled very considerably the minds of early astronomers. In

the first place, instead of keeping in a fixed position with regard to other stars, it moves among

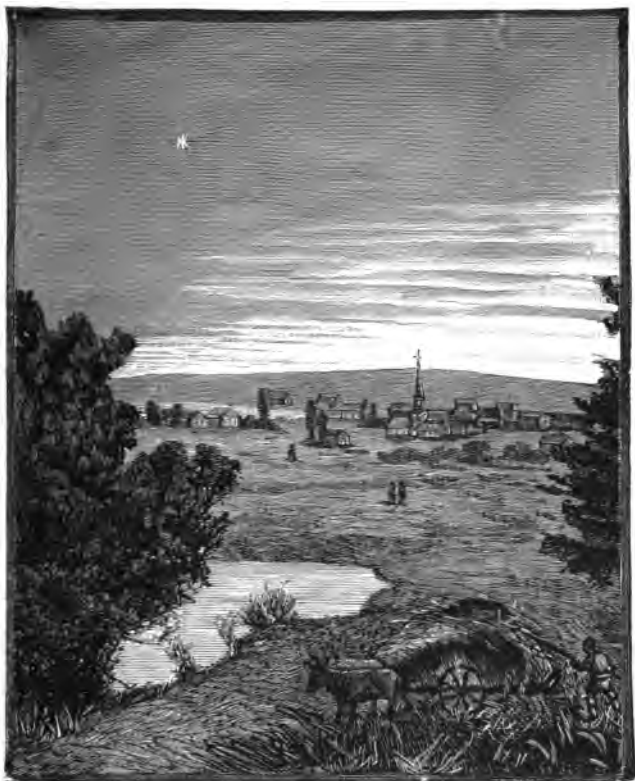


FIG. 23.—Venus, the evening star. Venus can never be seen more than 47° away from the sun.

them, like the sun and moon. To-night it is near one star, to-morrow its position has slightly changed, and the next day a further difference is observed. Unlike the sun and moon, however, this

shifting star does not roll majestically round the heavens in one direction. It moves slightly towards the east, then stops for a few days, as if undecided as to the proper course to take, goes towards the west, again "halts between two opinions," and eventually determines to move eastward, after which the vacillations are repeated. But though the star moves towards the west at times, it shows a decided preference for the east, the swing eastwards being always greater than that westwards. In course of time, then, the Evening Star must make a circuit of the heavens in the same direction as that in which the sun and moon move. What is more, the line of travel almost coincides with the ecliptic—with the path of the sun.

When the relation of the Evening Star to the sun is noticed, another strange variation is found. If observations are commenced when the star sets about three hours after the sun, it will soon be noticed that the difference between the two times of setting is gradually becoming less. From three hours the difference diminishes to two hours, to one hour, to half an hour, and eventually the star is lost in the sun's light, and we can follow it no longer. Shortly after this time, a "Morning Star" appears near the sun. The earliest Greeks knew this object by the name of Lucifer, the light-bearer. The distance between the star and the sun increases, and, as a consequence of this, the difference between the times of their risings increases also. When the star precedes the sun by about three hours, the limit is reached. It then begins to swing back towards our luminary until it is again lost to sight. A few weeks pass, and then an evening star is again seen very near the sun, and as time goes

on it swings out towards the east, setting longer and longer after the sun, until the previous difference of three hours is attained.

The first idea with regard to "morning" and "evening" stars would be that they were entirely different bodies. But when the birth of one had always been found to follow the death of the other, the speculation must have arisen as to whether the two stars were not one and the same object. This is really the case; Hesperus, the evening star, and Lucifer, the morning star, represent Venus seen under different circumstances.

In addition to Venus, there is another object which moves among the stars, now this way, now that way, now halting. Like the Evening Star, "the star of love and rest," this body travels round the zodiac in a series of loops. It swings from one side of the sun to the other, but does not get so far away as Venus. As a morning star, the Greeks knew the object by the name of Apollo. When it appeared in the evening its name was Mercury, "the swift messenger of the gods." On account of the small swing on either side of the sun the two bodies never set long after one another. The greatest difference of time between the two risings or settings is less than two hours, and the average difference is about an hour. In our latitude Mercury is very rarely seen, but in Egypt, and other places where the skies are clear and the duration of twilight is short, he is a conspicuous object.

Venus and Mercury move among the stars, like the sun and moon. Three other bright objects were observed by the ancients to behave in the same peculiar manner. The date of the discovery of this

motion is anterior to the time of which we possess any historic record. The cuneiform inscriptions of Babylonia and the hieroglyphics of Egypt show that the "wandering stars" or "planets" were familiarly known at least 2000 years before the commencement of our era, and no mention is made of the astronomers who first discriminated them from other celestial objects. Let us endeavour to trace the course of observations which would lead to their discovery.

Attention would be attracted to a star-like body which, though perhaps not brighter than other stars, differed from all of them in the fact that it did not twinkle appreciably. The object would be watched night after night, and would be found slowly to change its position on the celestial vault. These complicated motions must have perplexed early observers beyond measure, and only after records of many years of observation had been accumulated would it appear that they were governed by any law. Jupiter—the brightest of the wanderers—would be seen due south at midnight. He then occupies the opposite point in the heavens to that in which the sun is at the time, and is therefore said to be in "opposition." As he moves slightly westward among the stars, the sun moves eastward through a much greater distance. And the time comes when Jupiter is seen in the west at sunset; is almost lost in the twilight glows; is drowned in sunlight. When this occurs, the planet and the sun rise together, south together, set together, the lesser light is assimilated by the greater, and the two bodies are said to be in "conjunction." A separation soon occurs. Jupiter becomes visible in the early morning,

just before sunrise. Two, three, or four hours before the sun he appears above the horizon, and after thirteen months is again due south at midnight. Hence at intervals of thirteen months the sun, Jupiter, and the earth occupy the same relative positions,—but not with respect to the stars. If Jupiter is observed near a star at any opposition, he will be found to the east of it at the next opposition, and still farther east at the following one. It is only after eleven midnight southings that the star and the planet are in the same relative position.

Another planet known in prehistoric times was named Saturn by the Greeks. His movement among the stars is slow and almost imperceptible. A red-coloured planet is distinguished by the name of Mars—the god of war. This planet has a rapid and apparently a very irregular movement among the stars (Fig. 24).

Mercury and Venus can only be seen a few hours before sunrise or after sunset. They differ in this respect, therefore, from Jupiter, and Saturn, and Mars, which are seen at all hours of the night. But the motions of all these bodies are characterised by similar peculiarities. Each glides round the zodiac, now advancing in an eastward direction, then retiring back a little, and afterwards advancing to a position in front of the starting-point, to begin the performance afresh. Each changes considerably in brightness and in apparent size, Mars, Jupiter, and Saturn being largest and brightest when in opposition. And, most important fact of all, the planets are always seen close to the ecliptic.

Planets are, therefore, bodies which move in the heavens like glow-worms crawling along the face of a solid revolving vault sparkling with brilliant lights. They appear to be carried round with the firmament from east to west, and at the same time to have a motion of their own. The ancients recognised five such bodies having a star-like appearance,

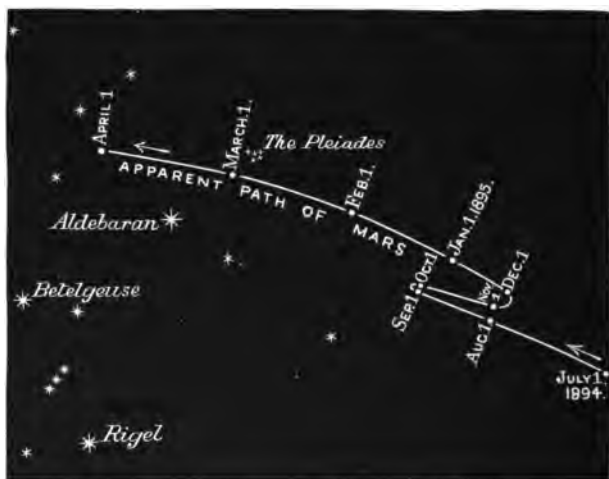


FIG. 24.—Apparent path of Mars among the stars during 1894 and 1895.

namely, Mercury, Venus, Mars, Jupiter, and Saturn. These, with the moon, appear to travel round the heavens in almost the same path—the ecliptic—as that in which the sun apparently journeys, thus indicating that a relation exists between them all. For this reason, the sun and moon were formerly classified as planets as well as the other wanderers, though they are not referred to as such at the present time. Since the invention of the telescope two large

planets, known as Uranus and Neptune, have been discovered, and a host of smaller ones, all of which acknowledge the sun as their ruler.

SYNOPSIS OF CHAPTER IV

Apparent annual movements of constellations.—The stars rise, south, and set four minutes earlier every night, so the constellations visible at midnight change throughout the year. This fact was used by the ancients to mark the seasons.

The sun appears to move in an eastward direction among the stars, thus producing the change in the constellations visible at midnight.

The ecliptic is the apparent path of the sun among the stars.

The zodiacal constellations are those situated within about eight degrees on both sides of the ecliptic.

Declination.—The angular distance of a body from the celestial equator is known as declination. The celestial pole, and therefore the celestial equator, are at fixed heights above the horizon of a place.

Changes of the sun's declination.—The sun only appears to travel along the celestial equator twice a year—at the equinoxes. At the solstices he has his greatest north and south declinations. The variation causes the points of rising and setting to change during the year.

The motion of the moon is very nearly in the ecliptic, but a revolution is accomplished in a month instead of a year.

Planets appear to the naked eye like stars, but when watched for some time they are seen to move around the ecliptic in loops.

CHAPTER V

THE ORDER OF THE UNIVERSE

HAVING described the motions of the sun and moon, and the apparently capricious loops traced upon the sky by the planets, it behoves us to enquire into the cause of these phenomena. When the motions had been discovered, theories were propounded to account for them. For many centuries it was believed that "the outer sky is solid and crystalline," and that the stars are "fixed to its surface like studs." This crystalline sphere was said to surround the earth. Evidently the sun could not be fixed in the star-sphere, or he would always occupy the same position with reference to the stars. A second sphere was therefore invented which carried our luminary and revolved at a slower rate from east to west than the sphere of the stars. Six other hollow spheres were supposed to carry the five planets and the moon, all of them being assigned a particular rate of revolution, and all perfectly transparent (Fig. 25). Immovable, in the centre of the spheres, the earth was placed. It will be at once concluded that this theory does not explain the observed facts. How, for instance, could the eastward and westward motions of the planets and the stationary points be produced if



the bodies were fixed on hollow globes constantly revolving in one direction? To explain these differences Ptolemy supposed that the motions took place not in circles but wavy loops known as epicycles. Even

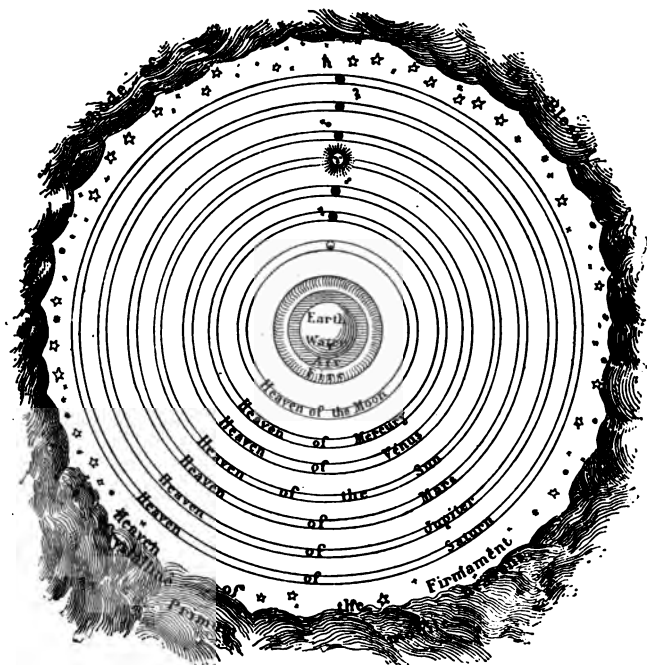


FIG. 25.—Ptolemy's theory of the arrangement of the sun, moon, and planets.

then there were many facts unaccounted for, and the cumbrous machinery at last contained seventy-five crystalline globes, one within the other.

The Ptolemaic theory of the universe was fundamentally wrong, for it assumed that the earth was situated in the centre of all creation. Pythagoras and

Aristarchus had made the earth a subordinate body revolving round the sun with five other bodies, but their views did not meet with favour. The complicated system of Ptolemy held its own until the fifteenth century, and during that time no astronomer worthy of the name was produced. At length there came a man whose work revolutionised the accepted gospel of astronomy.

Copernicus was born at Thorn, in Poland, in 1473. He was bold enough to attempt to explain celestial motions on the supposition that the earth was a spinning globe travelling round the sun with the planets. The acceptance of this idea meant that the earth must be pulled down from her position in the centre of the universe, and bodies which were supposed to be subservient to her were to be exalted. Naturally the theory was repugnant to mankind, and Copernicus and his followers were accused of irreligion, just as Aristarchus was eighteen centuries previously. Copernicus well knew that the theory of the earth's movements had been formulated long before his time. But though the opinion had been held and taught, it was so much less gratifying than the Ptolemaic doctrine that the very remembrance of it had almost become lost in the mist of ages. Copernicus worked at the idea for thirty years and gave it to the world just before he died. His anxiety as to the manner in which the theory would be received was not without foundation. The theory was condemned. Facts which could not be confuted by argument were held up to ridicule, and believers in the truth were crushed by persecution. Thus it was that Galileo had to renounce the observations of a lifetime, while Giordano Bruno, fearless,

and with only the courage of his convictions to support him, endured burning at the stake.

The arrangement of bodies, according to the Copernican theory of the universe, was stated by the originator in words of which the following is a translation :—

“In the highest plane is the sphere of the fixed stars, an immovable sphere, which surrounds the whole of the universe. Among the movable planets the first is Saturn, which requires thirty years to make its revolution. After it Jupiter accomplishes its journey in twelve years; Mars follows, requiring two years. In the fourth line come the earth and the moon, which in the course of one year return to their original positions. The fifth place is occupied by Venus, which requires nine months for its journey. Mercury occupies the sixth place, whose orbit is accom-

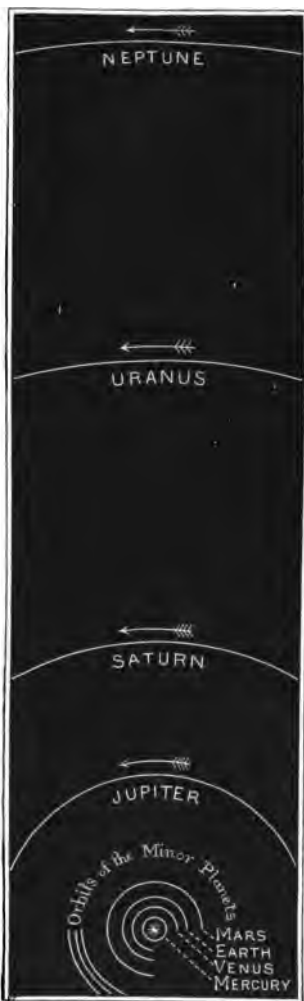


FIG. 26.—To show the relative sizes of the orbits of the planets. The diagram is drawn to true scale.

plished in eighty days. In the centre of all is the sun. What man is there, who in this majestic temple could choose another and better place for that brilliant lamp which illuminates all the planets with their satellites? It is not without reason that the sun is called the lantern of the world, the soul and thought of the universe. In placing it in the centre of the planets, as on a regal throne, we give it the government of the great family of celestial bodies" (Fig. 26).

Now let us see how this comparatively simple arrangement is competent to explain all the apparent motions described earlier in the last chapter. Of the daily rotation of the heavens nothing need be said, for we have previously shown that it is but a reflection of the rotation of the earth. This was one of the first principles of the Copernican theory. To begin with, we have the fact that the sun appears to travel round the heavens in a year. As an illustration of the kind of motion, let the sun be represented by a lamp fixed in the centre of the arena of a large circus, and the earth by a spinning globe moving round it, while the bright eyes of spectators take the place of stars. If the globe travel along its track in the opposite direction to that in which the hands of a watch move, spinning in this direction as it does so, two apparent or reflected motions must be produced, one the result of rotation, the other the result of revolution. The rotation, by alternately turning different parts of the globe towards the lamp and away from it, causes phenomena analogous to those of day and night. On account of the motion of revolution the lamp is constantly being projected upon a different part of the

audience. And by imagining that while going once round the ring the globe makes $365\frac{1}{4}$ spins, we get a case exactly analogous to that of the sun and earth. In $365\frac{1}{4}$ days the sun travels completely round the ecliptic. In reality he does not move in this manner, but only appears to move, on account of the real motion of the earth round him. The yearly change in the positions of constellations at midnight is brought about by the fact that the earth is situated between the sun and different parts of the celestial sphere on every night of the year, and only occupies the same point of her path once a year.

The yearly variation in the sun's apparent position with respect to the horizon remains to be explained. Returning to the circus illustration, let us suppose that the globe not only travels round the lamp in a perfectly level path, but that it spins bolt upright in this path. The centre of the lamp would then be continually in a line with the equator of the globe. An imaginary small being situated on the equator would therefore have the lamp directly overhead once during a rotation. Similar figures in other parts of the globe would be turned towards the light, but the centre could never be straight above them. The highest point reached during a spin would become less and less as the hypothetical person moved away from the equator, and at the poles the centre of the lamp would continually be on their horizon. Now let us change this condition of things.

Suppose the axis of spin of the globe not to be perpendicular to the level in which the motion takes place, but inclined to it. And, to concentrate our ideas, suppose that the globe is in front of one

of the audience, with its axis pointing upwards and outwards to the selected spectator. The centre of the lamp will then not be in a line with the equator but with a point below it. As the globe moves round the light, still keeping its axis pointing in one direction, the centre of the lamp gets more and more in a line with the equator, and when the tilt is neither towards nor away from the light, the lamp is on the equator. Continue the journey for another quarter of a revolution and the centre of the lamp is as much above the equator as it was previously below it. Another quarter of a revolution and the light is again on the equator, and it then moves downwards until the starting-point is reached.

Thus, owing to the tilt of the globe at a constant angle the light strikes the surface at different angles throughout the journey. A pigmy on the globe would see the light move up and down during a revolution, just as we observe in the case of the sun. Indeed, the variations in the sun's noonday elevation are caused by the fact that the earth does not rotate with its equator lying in the level in which revolution round the sun occurs, in other words, the axis of rotation is not perpendicular to the plane of revolution. If it were so, the path of the sun across the sky would be the same every day in the year, and the succession of seasons would be unknown. The amount of inclination is very nearly constant, and the Pole-Star happens to be near the point towards which one end of the axis of rotation is directed.

When it is winter to us in England, the north pole of the earth is tilted away from the sun and the south pole is directed towards him. The sun-

beams pierce our atmosphere very obliquely, hence much of their intensity is absorbed before they reach the earth's surface. Further, we are only in the beams for a short time, the night is longer than the day, and we are losing heat into space for the greater part of a rotation. The loss by night exceeds the meagre supply by day, and, as a result, cold weather sets in. At this time the north polar regions are

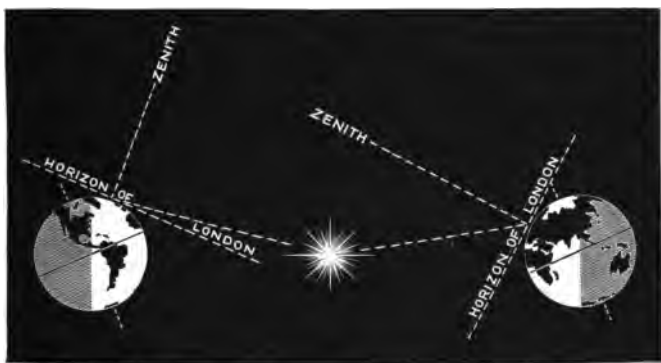


FIG. 27.—To explain why the mid-day sun, seen from London, is low down in the sky in mid-winter and high up in mid-summer.

in darkness. The sun can only illuminate about half the earth at once, and if the terrestrial axis were not inclined, the bright half of our globe would extend from pole to pole. As it is, during our winter the north polar regions are turned away from the sun and do not receive any of his direct light (Fig. 27).

When the earth is passing from winter to spring, the sun is approaching the equator, and at the spring equinox he is on the equator. We then have the condition which would obtain if the axis of rotation

were perpendicular to the plane of revolution, namely equal days and nights all over the world.

From spring to summer, the sun is moving north of the equator, on account of the axial inclination of the earth, and when the highest point is reached, the northern hemisphere is turned towards the sun and the southern hemisphere away from him. The sun's rays then pierce our atmosphere almost vertically, and we receive them for the greater part of twenty-four hours, so warmer weather occurs. The north polar regions then remain in sunlight during a complete rotation, while similar regions near the south pole are in darkness.

At the summer solstice the noonday sun is high above the horizon of London, and even at midnight he is only a short distance below it. Almost the whole of his apparent path takes place above the horizon. By travelling to the north of Scotland at this time of year, we find that it is possible to read a paper at midnight (Fig. 28). And by going still farther north a point is reached at which the sun does not sink below the horizon at all but is visible at midnight. Excursions are frequently run to Norway in June to enable people to witness this strange appearance of a "midnight sun."

From our summer solstice, the sun approaches the equator, and crosses it at the autumnal equinox. He goes on describing a lower path across the northern sky until the winter solstice is again reached, and his rays strike the surface most slantingly. It will therefore be seen that the succession of the seasons is produced by the earth moving round the sun with its axis inclined and continually pointing in one direction,

thus causing inequalities in the lengths of the days and nights during the year, and a difference in the angle at which the rays strike the surface.



FIG. 28.—The midnight sun. In lat. $66\frac{1}{2}^{\circ}$ N. the sun does not set at the summer solstice (20th June), and is due north on the horizon at midnight.

Since the sun is on the equator twice a year—at the equinoxes—and at his greatest distance above or below it at the solstices, by measuring the difference between the noonday elevation at an equinox and solstice, the inclination of the equator to the plane in

which the earth moves round the sun is found. At the time of our summer solstice, the noonday sun is directly overhead in latitude $23\frac{1}{2}^{\circ}$ north, at our winter solstice he is overhead in latitude $23\frac{1}{2}^{\circ}$ south. The inclination is therefore $23\frac{1}{2}^{\circ}$. It is known as the "obliquity of the ecliptic," the earth's plane of revolution being the plane of the ecliptic (Fig. 29).

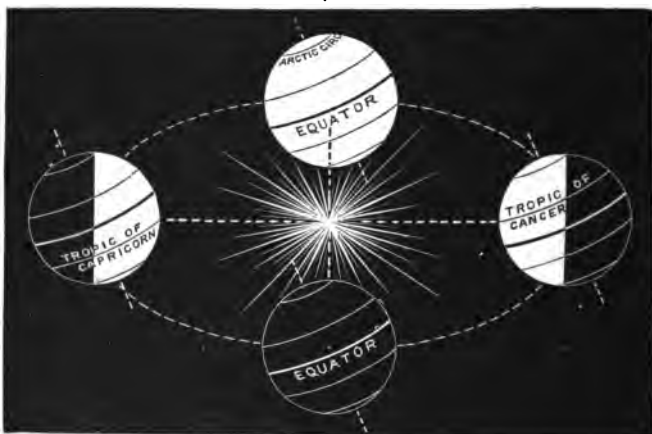


FIG. 29.—To explain why the sun's declination varies during the year. In our winter solstice (21st Dec.) the sun is directly overhead in $23\frac{1}{2}^{\circ}$ south latitude (the tropic of Capricorn); on 20th March it is directly over the equator; on 20th June it is over the tropic of Cancer (lat. $23\frac{1}{2}^{\circ}$ N.); and on 23rd Sept. it is again on the equator. (See also *Frontispiece*.)

The celestial equator is midway between the two celestial poles—the points about which the heavens seem to turn—and the ecliptic is the apparent path of the sun. One is the projection of the earth's equator upon the sky; the other is the projection of the plane in which the earth revolves. If we imagine two circles traced upon the celestial sphere to represent the equator and ecliptic respectively, the

greatest angular distance between the two will be $23\frac{1}{2}^{\circ}$. Since the circles stretch completely round the sky they must cross one another at two points. The sun is at one of these points at the spring equinox, and is projected upon the opposite one at the autumnal equinox. It must be at once understood, however, that the positions of the equator and the ecliptic, and therefore the positions of the points where they intersect, are quite independent of the places of stars. If for any reason the plane in which the earth revolves round the sun changes its position, the ecliptic must take up a different position with respect to the stars. This applies also to the celestial equator and to the points of intersection of the two great circles of the sky.

The ecliptic can be considered to have a fixed direction, but the points where the equator cuts it slide along it towards the west at the rate of one degree in about seventy-two years, or $52\cdot2$ seconds of arc in one year. At the spring equinox of this year (1894) the centre of the sun was in front of a particular point on the celestial sphere; in 1895 at the same equinox it will be $50\cdot2''$ to the west of that point, and in seventy-two years one degree to the west of it. This slow westward movement of the equinoctial points is known as the "precession of the equinoxes." On account of it these points travel completely round the ecliptic in about 26,000 years. Let us consider what this means.

The signs of the zodiac start from the point occupied by the sun at the spring equinox. This point is slowly shifting, hence the signs must shift. But the zodiacal constellations—the stars that happen to lie near the

ecliptic—are not affected by this movement, and the result is that the *signs* of the zodiac are being carried round the *constellations* of the zodiac. At one time the sun was projected upon the constellation Aries,—the Ram—at the spring equinox, and passed through the other zodiacal constellations in turn until “the Fishes with glittering tails” were reached. But time has changed all that. The constellation Pisces—the Fishes—is now behind the sun at the spring equinox; in other words, the *sign* of Aries now coincides with the *constellation* Pisces, and all the other signs have backed in the same manner along the zodiacal constellations.

Another effect of precession is to cause the poles of the heavens to describe circles round the poles of the ecliptic in about 26,000 years, keeping at a constant distance of $23\frac{1}{2}^{\circ}$. At the present time there happens to be a bright star near the north celestial pole, and we call it the Pole-Star or Polaris. But, on account of precession, all stars about $23\frac{1}{2}^{\circ}$ from the poles of the ecliptic become pole stars in a period of 26,000 years. About 3700 years ago the star α Draconis was near the north celestial pole, and 14,000 years hence α Lyrae will be doing polar duty (Fig. 30).

We have said that the plane in which the earth revolves can be considered to retain a constant direction. The effects of precession must therefore be brought about by a movement of the plane of the earth's equator. It will be remembered that in illustrating the movement of the earth around the sun by a spinning globe moving around a lamp in the arena of a circus, the axis of rotation of the globe was supposed to point constantly to one of the audience. As a

matter of fact, the direction in which the axis pointed should not have been absolutely constant. For a dozen or even for fifty journeys round the lamp no difference of direction need be given to it, but after

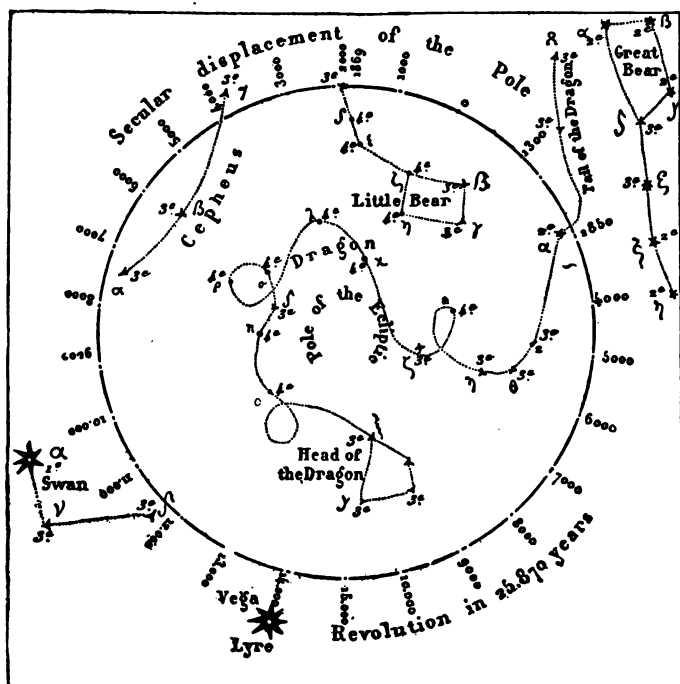


FIG. 30.—Owing to precession the celestial poles revolve round the poles of the ecliptic once in 25,870 years.

the globe has made about 6500 journeys the axis should point to a spectator on the same row as the former one, but situated at one quarter of the distance round the circus; after 13,000 journeys it should point to a spectator exactly opposite the original one,

and in about 26,000 journeys it should have the same direction as at the commencement of the cycle. All the individuals on a particular row would thus become pole stars in the course of 26,000 revolutions of the globe, presuming that they had the patience to watch the performance long enough. This is exactly analogous to what takes place in the case of the earth. The axis of rotation remains almost constant in direction for a few years, but in a cycle of 26,000 years each extremity describes a circle, thus producing the change of pole stars to which reference has been made.

In our illustration, the axis of the globe pointed to a particular row during the whole cycle of change; in other words, its inclination to the plane of revolution was kept constant. Suppose now that the arena were filled with water up to the level of the centre of the lamp. When the axis of the globe pointed to a particular spectator, the equator would cut the water-level at two points, and the line connecting these points would have a particular direction. As the axis turned round, this line would have its direction altered, and would be brought back to the original direction after 26,000 revolutions of the globe. The inclination of the equator to the water-level represents the inclination of the earth's equator to the ecliptic. This is subject to a variation so small that we can leave it out of consideration. But as the equator has its direction changed, the line of intersection between its plane and the ecliptic plane is also moved round. On this account the points at the extremities of the line—the equinoctial points—travel round the ecliptic in the same time that the celestial poles gyrate round the poles of the ecliptic.

It has been shown that the earth is bulged out at the equator. The attraction of the moon and sun upon this mass of superabundant matter causes the precession of the equinoxes. If the earth were a perfect sphere, the axis would remain pointing in one direction throughout time; as it is not, the moon and sun try to pull the equatorial protuberance into the level of the ecliptic. And were the earth not a spinning ball its equator would shortly settle down in the ecliptic plane. But a rotating body has a kind of will of its own; hence the earth obstinately refuses to obey the levelling dictates of the greater and lesser lights, and only responds to their actions by majestically changing its direction of rotation.

When the movements of the earth are understood, the apparent motions of all the heavenly bodies are easily followed. An observer on the sun would see the planets moving round the sky in one direction at different rates. We on the earth do not see the workings of our system from a fixed point, but as from a travelling observatory. It is for this reason that the planets appears to travel round the ecliptic in loops. Take the motion of Jupiter as an example. Our big brother performs a revolution round the sun in about twelve years. Hence, while the earth goes completely round its orbit Jupiter only traverses one-twelfth of his path. Suppose the planet to be seen almost in a line with a particular star at any time. Three months later, the earth will have travelled along one-quarter of its annual journey, and Jupiter therefore appears projected to the side of the reference star. There is an apparent stationary point, and then the planet moves back to the star until he is in conjunction.

The movement of the earth to the opposite side of its orbit causes the planet to appear on the opposite side of the star. Another stationary point occurs when the earth is moving towards or away from the planet, instead of moving across the direction in which he is seen, and then the apparent movement is towards the original position. But the reference star is not reached. While the earth has been going round the sun, and causing Jupiter apparently to swing to and fro, the planet itself has really moved a short distance eastwards; hence the position in which he is found after a period of this character is to the east of the previous one. Similar reasoning applies to the motions of any of the planets revolving round the sun in orbits outside that of the earth. (For path of Mars see Figs. 24 and 31.)

In the case of the two "inferior" planets Mercury and Venus, the appearances are different. We have shown that neither of these planets are seen beyond a certain distance from the sun. The cause of this is easily understood when it is remembered that Mercury and Venus revolve round the sun in orbits inside that of the earth. If, for simplicity, we consider the earth not to have an orbital motion, we should see the two inferior planets circling round our luminary, now to the west of him as "morning" stars, now to east as "evening" stars, while they would be sometimes behind him and sometimes between us and his light. The greatest angular distance between the sun and either Mercury or Venus occurs when these bodies are moving towards or away from the earth, when, in fact, we see them separated from the sun by the radii of their respective orbits. Since the earth is in

motion, we do not see the inferior planets simply swing to and fro in straight lines, but an apparent motion is superadded to their real motion, and the result is that planetary loops are traced upon the celestial sphere.

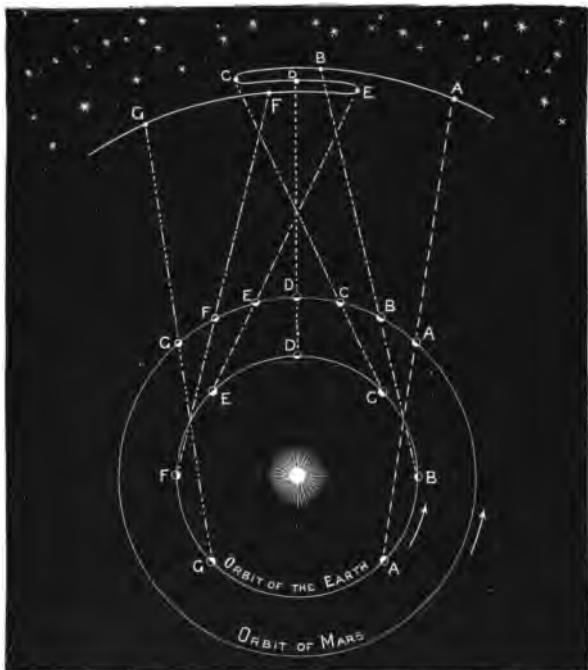


FIG. 31.—To explain the apparent path of Mars among the stars. It will be seen that the motion of the earth from A to C while Mars moves from A to G in its own orbit causes the latter to appear to move in a loop among the stars.

As soon as the Copernican theory had been propounded, it was seen that the phenomena presented by Mercury and Venus would be a test of its validity. For if these planets revolve between the earth and the sun, and only their sides are illuminated which face

the sun, they must go through changes like the moon. And this is really found to be the case (Fig. 32). When between the sun and us, they appear as small black spots upon his face. As they pass to one side to become morning stars, they are at first crescent-shaped, and when the greatest angular distance is reached they have a half-moon appearance—we see them side-faced, as it were. From this time they pass to a full-moon appearance, then to half again, as they are seen on the opposite side of the sun, and then as they are swinging round to pass between us and the sun again

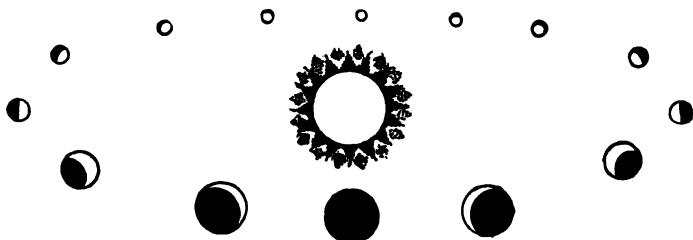


FIG. 32.—To show the appearances presented by the planets Mercury and Venus, both of which revolve round the sun at a smaller distance than the earth.

the half is transformed into a crescent. We can imitate these changes in a very simple manner.

Let a lamp represent the sun, and let an earthly Venus walk round it with her face towards the light to imitate the illuminated side of the planet Venus. If we stand at a greater distance from the lamp than our companion, we get the conditions which actually prevail in our system. When the young lady who has consented to represent the goddess is between us and the lamp, we get a back view, and see nothing of her "bright and shining countenance." As she moves round the lamp, more and more of her illuminated

features become visible, and when she has travelled one-quarter of the distance round, we see her side-face. Another quarter of a revolution and the whole of her face beams upon us. She then passes on and once more gives us her face in profile, and afterwards the illuminated outline becomes crescent-shaped, until the back view is regained (Fig. 33).



FIG. 33.—To illustrate the phases of Venus and Mercury.

In the time of Copernicus, the telescope had not been invented, so it was not possible to test his theory by observing the facts. Galileo, in 1610, using a telescope of his own construction, found that Venus underwent the changes we have indicated, and his observations helped to establish more fully the Copernican theory in the minds of the people who were

already disposed to believe it. On somewhat rare occasions Venus and Mercury are seen as black spots on the sun's disc, this fact affording another proof that these planets are moving between us and the sun.

Jupiter was one of the first planets examined by Galileo. Four small objects were seen near the planet and considered at first to be stars. But when the observations were further extended, it was noticed that these objects did not remain fixed like the stars, but moved with the planet on the celestial sphere. They accompanied Jupiter in his wanderings, and evidently belonged to the planet. It appeared, in fact, that Jupiter was the centre of a family of four small bodies, just as the sun is the centre around which the planets themselves move. This afforded another argument in favour of the Copernican theory. The attendants or satellites of Jupiter bear the same relation to the planet that the moon does to the earth. In fact, he was found to be furnished with four moons to our one.¹

Two tenets were implicitly believed in by the promulgators of astronomical systems. First, that all the planets moved uniformly in their respective orbits; secondly, that the orbits were circular in shape. These theories were even accepted by Copernicus, but they were destined to be overthrown by the observations and calculations of an astronomer named Kepler, about 1610. Kepler showed that the planet Mars moved not in a circle but in an ellipse, and that its rate of motion depended upon its position in that elliptical orbit. From a further investigation of planetary motions, he was led to enunciate three laws governing

¹ A fifth satellite of Jupiter, nearer to the planet than any of the others, was discovered in 1892.

the whole of the sun's family. The first of these asserts that "each planet moves in an ellipse, of which the sun occupies one of the foci." To understand this statement it is necessary to have a clear idea of the properties of an ellipse.

If a pin is stuck into a piece of paper, with a loop of thread over it, and a pencil is held in the other end of the loop so that the thread is tight, a circle can be

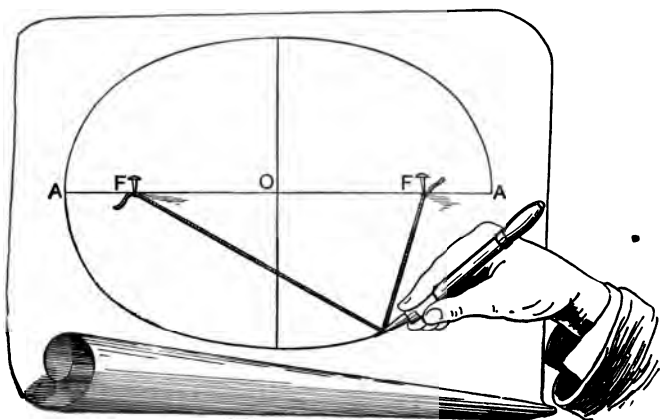


FIG. 34.—Showing how to draw an ellipse. FF are the foci of the ellipse.

drawn by moving the pencil round the pin. Now let two pins be fixed in the paper at a short distance from one another, and again carry the pencil round with the loop over both pins. An ellipse instead of a circle will be traced upon the paper (Fig. 34). When the pins are near together, the ellipse will scarcely be distinguished from a circle, but as they are put farther apart a more and more elliptical figure will be produced. The positions of the pins when any ellipse is



drawn in this manner mark the two foci of that particular ellipse.

According to Kepler's first law the sun is situated in a focus of the ellipse described by each planet. It follows from this that each planet is continually changing its distance from the sun. At one point of the orbit a planet is nearest the focus in which the sun stands, at the

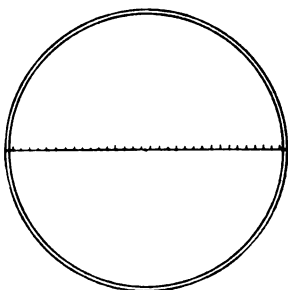


FIG. 35.—To illustrate the yearly variation in the apparent size of the sun. The inner circle represents the size of the sun on midsummer day, and the outer the relative size in mid-winter. The diameter is divided into minutes of arc.

opposite point it is most distant from it. We can test this law very easily in the case of the earth. If our globe moved round the sun in a circle, the apparent size of the sun at noonday ought always to be the same. But it is not. Measurements of the sun's apparent diameter show a gradual increase from summer to winter, and then a decrease back to summer again. The inference from this must be that the earth

is nearer the sun in winter than in summer, unless, indeed, we accept the very improbable supposition that our luminary contracts and swells in size in the course of a year (Fig. 35).

Kepler's second law states that "the imaginary line connecting a planet with the sun sweeps over equal areas in equal periods of time" (Fig. 36). This is equivalent to saying that the planets do not move uniformly in their orbits. If the planets moved with uniform velocity in circles round the sun, this law would necessarily follow. Each planet would then behave as if it

were fixed to one end of a gigantic watch-hand centred at the sun. Hence, in equal intervals of time, the angle through which a planet moved would be the same, no matter what position the watch-hand might occupy. And hence the area included between two positions of the hand separated by an equal interval would always be the same, just as the area swept over by the minute-hand of a watch in five minutes is the same in all parts of the dial. But the orbits of planets are ellipses,

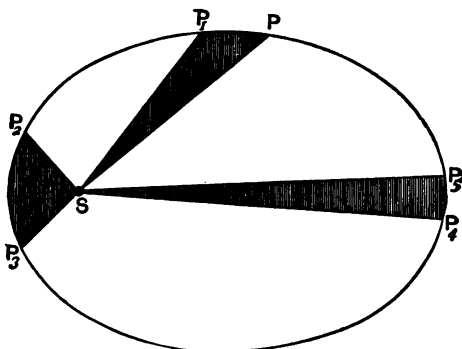


FIG. 36.—“The imaginary line connecting a planet with the sun sweeps over equal area in equal times.”

not circles. If equal angles were passed over in equal times, the areas described by the line joining a planet to the sun would differ at different parts of the orbit. Thus, if a planet travelled through 10 degrees with respect to the sun in a certain time, whatever its position, when it was near the sun the area described by the imaginary line connecting the two bodies would be less than when more distant. The greatest difference would be between the areas described in equal times when nearest and when most removed from the sun. These extreme cases ~~are~~

illustrated by supposing the planet to be fixed on the large hand of an enormous watch when most distant from the sun, and on the small hand when at its nearest point. Clearly, the area swept over by the former in any time is greater than the area which the latter would pass over in describing the same angle. But observations show that the areas are equal, and for this to be the case, the small hand must travel through a greater angle than that through which the large hand passes in the same time. In other words, the nearer a planet is to the centre of motion—the sun—the quicker is its rate of motion. And, in whatever part of its orbit a planet may be, “equal areas are swept over in equal times.” Here again we can easily run the facts home. The earth is nearest the sun during our winter, it should therefore move fastest at that season. But the motion of the sun in the ecliptic is a reflection of the earth’s real motion. Hence, according to the law under consideration, the sun ought not to move uniformly in the ecliptic. And he does not. In passing from the autumnal to the spring equinox, that is, from 22nd September to 20th March, the sun takes 179 days, whereas in travelling from the spring to the autumnal equinox the interval is seven days longer.

Kepler’s first and second laws refer to the motion of one body round another. His third law states precisely the relation between rate of motion and distance. It asserts that “the squares of the times of revolution are proportional to the cubes of the mean distance.” The square of a number is that number multiplied by itself. Thus, the square of 2 is 2×2 , that is, 4; the square of 3 is nine; of 4,

16; and so on for any other number. The cube of a number is the square again multiplied by the number. Thus, the cube of 2 is $2 \times 2 \times 2$, that is 8; the cube of three is 27; of 4, 64; and so on. The time of revolution of a planet is the exact time taken to travel round the sun, and the mean distance is the average distance. It is the radius of the circle which could be formed from each planetary ellipse.

With these explanations the meaning of Kepler's third law will be better understood. The law shows that the motions and distances of any two planets are proportional, a fact which is of the utmost importance in astronomy. As an example of its use, let us suppose the period of Saturn to have been found to be $29\frac{1}{2}$ years, and we require to know how much his distance from the sun exceeds the earth's distance. The period of the earth is one year. Hence Saturn's period exceeds the earth's period in the ratio of the square of $29\frac{1}{2}$ to the square of 1, that is, the two periods are in the proportion of 870 to 1. But the cubes of the distances are also in this proportion, in other words, the cube of Saturn's distance is 870 times greater than the cube of the earth's distance. To determine how much this exceeds the distance of the earth, we have to find the number which when multiplied by itself, and then again multiplied, produces 870. This proves to be very nearly $9\frac{1}{2}$. Saturn is therefore at a distance from the sun nine and a half times greater than the earth's distance from the same body. Hence, as soon as the period of a planet has been determined, the distance in terms of the earth's distance can be calculated by the application of this "harmonic law."

These laws are accurate statements of facts

established by observation, but they do not throw any light upon the cause which makes the planets obey them. Kepler had the idea that the sun exerted a strong magnetic influence upon the planets, and so kept them in order, but it was left to Newton to prove that the motions could all be accounted for by a single law—the law of gravitation. “Every particle in the universe attracts every other particle with a force which is proportional to their combined masses and inversely proportional to the square of the distance between them.” The planets move fastest when nearest the sun, the reason being that the force of gravitation has then its greatest value. The law shows that the planets are pulled straight towards the sun, and if they had no motion of their own, they would be slowly drawn into him, like silly moths into a lamp, and be consumed. Fortunately, the earth and the other planets have a tendency to keep in a straight path, and this preserves them from destruction. A kind of compromise is struck between falling into the sun and leaving him altogether, and the orbit represents the arrangement arrived at. The law of gravitation is sufficient to account for the course a planet takes when once started, so it is not necessary to assume the existence of any external power or machinery to keep our system going. As to the cause of gravitation itself, nothing has yet been determined. Since the time of Newton many investigators have studied this matter, and also the mode in which gravity acts through space, but no definite results have been obtained. Kepler’s laws are consequences of the law of gravitation, but the real nature of gravitational effects remains to be explained.



SYNOPSIS OF CHAPTER V

The Ptolemaic theory of the universe assumed that the celestial sphere, the sun, and the moon, revolved round the earth in circles, while the planets went round in epicycles.

The Copernican theory fully explains the facts of observation. Its main principles are : (1) That the earth rotates on her axis, thus causing the apparent diurnal motion of the heavens ; (2) that the earth is a planet revolving round the sun in a year, thus producing the apparent annual movement of the sun in the ecliptic and the apparent loops described by planets ; (3) that satellites, like the moon, revolve round their primaries.

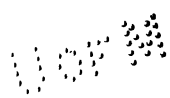
The inclination of the earth's equator to the plane of the ecliptic is $23\frac{1}{2}^{\circ}$. On account of this and the earth's revolution we get : (1) The noonday altitude of the sun changing throughout the year ; (2) an annual variation in the positions at which the sun rises and sets ; (3) days and nights of unequal length ; (4) the succession of the seasons.

The annual changes of temperature are caused (1) by the unequal lengths of days and nights ; (2) by the sun's rays passing through the earth's atmosphere and striking the surface at different angles.

The inferior planets, that is Mercury and Venus, go through changes like the moon. The discovery of these phases went to confirm the Copernican theory.

Kepler's laws of planetary motion are : (1) The planets move in elliptical orbits having the sun in one of the foci ; (2) the areas swept over by the radius vector of each planet are equal in equal times ; (3) the squares of the periods of the planets are proportional to the cubes of their mean distances.

The precession of the equinoxes is a westward movement of the equinoctial points along the ecliptic at the rate of $50\cdot2''$ per annum. Results of this are : (1) the signs of the zodiac move backwards through the zodiacal constellations ; (2) the celestial poles describe circles of $23\frac{1}{2}^{\circ}$ radius round the poles of the ecliptic.



2007

INDEX

ALTITUDE, 18

Andromeda, constellation of, 12
 Angular measurement, 43
 Annual motion of sun, 60, 82
 Apparent motions of moon, 69; of
 planets, 75-77, 93; of stars, 14,
 36; of sun, 30, 36, 59, 82
 Apparition, circle of perpetual, 15
 Aquila, constellation of, 11
 Arc of meridian, 45-50
 Aries, constellation of, 90
 Ascension, right, 13
 Attraction of gravitation, 41, 52,
 104
 Auriga, constellation of, 13
 Axis of the earth, 39, 90

BASE-LINE, measurement of, 46
 Bootes, constellation of, 9

CANCER, tropic of, 88
 Canis Major, constellation of, 7
 Canis Minor, constellation of, 8
 Capricorn, tropic of, 88
 Cassiopeia, constellation of, 5
 Cavendish, 55
 Cepheus, constellation of, 5
 Circle of perpetual apparition, 15
 Conjunction, 74
 Constellations, 2
 Copernican system, 81
 Copernicus, 80
 Cygnus, constellation of, 11

DAWN and twilight, 38
 Day and night, 28
 Declination, 68
 Degree defined, 43; of latitude,
 49

Density, 56

Designation of stars, 3
 Diameter of the earth, 53
 Diurnal motion of the heavens, 14
 Draco, constellation of, 5

EARTH density, 56; diameter, 53;
 form of, 20; mass, 55; oblate-
 ness, 51; revolution, 100; rota-
 tion, 32; shadow on moon, 26;
 size of, 53

Eclipse of moon, 25
 Ecliptic, 62; obliquity of, 88
 Ellipse, 99

Equator, celestial, 16, 68, 85, 88,
 92; terrestrial, 49
 Equinoctial points, 92
 Equinoxes, 68, 86; precession of
 the, 89

FORM of the earth, 20 *et seq.*; of
 the earth's orbit, 100
 Foucault, 32

GALILEO, 1, 80, 97, 98
 Gemini, constellation of, 8
 Gravitation, 41, 54, 104

HARMONIC law, 103
 Hercules, constellation of, 10
 Horizon, 22

INFERIOR planets, 94

JUPITER, apparent motion of, 74,
 93; orbit of, 81

KEPLER, laws of planetary motion,
 98

